REPORT

Dokument-ID
NPSAG Report 11-004-02
ÅF id: 6034743-012

Version
1.0

Date
2015-03-17

Issued by
EXAM HRA WG

Sign

Project
2013050/6034743

Evaluation of Existing Applications and Guidance on Methods for HRA – EXAM-HRA

A Practical Guide to HRA

NPSAG Report 11-004-02

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Acknowledgements

The project team conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible. The contributing organizations are:

The contributing organizations are the Nordic PSA Group (NPSAG) in this project represented by Forsmark NPP (FKA), Ringhals NPP (RAB) and Olkiluoto NPP (TVO),), SSM, Vattenfall, the Finnish research program SAFIR, VTT, NKS, VGB, Brunsbüttel NPP (KKB), Krümmel NPP (KKK) and Mühleberg NPP (KKM).

We also appreciate the contributions from the working group members that have moved to other positions during the project: Ilkka Männistö, Jan-Erik Holmberg and Lisa Fritzson/Zamani. Further we thank Cilla Andersson, Ringhals NPP (RAB), for many useful comments during the review of the final reporting.

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LIST OF ACRONYMS/TERMS

Aleatoric	Parametric uncertainties
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
Category A	Pre-initiator actions
Category B	Initiator actions
Category C	Post-initiator actions
CBDT	Caused Based Decision Tree
CCF	Common Cause Failures
CDF	Core Damage Frequency
COI	Conflict of Interest
EFC	Error Forcing Context
ENSI	Swiss Federal Nuclear Safety Inspectorate
EOC	Errors of Commission
Epistemic	Modelling uncertainties
EPRI	Electric Power Research Institute
EXAM HRA	**E**valuation of e**X**isting **A**pplications and **M**ethods for **H**uman **R**eliability **A**nalysis
FGC	Failure Guaranteeing Condition
HEP	Human Error Probability
HFE	Human Failure Event
HMI	Human Machine Interface
HPLV	Human Performance Limiting Value
HRA	Human Reliability Analysis
HTA	Hierarchical Task Analysis
IAEA	International Atomic Energy Agency
MCR	Main Control Room
MCS	Minimal Cut Set
NRC	U.S. Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development
PRA	Probabilistic Risk Assessment, see also PSA
PSA	Probabilistic Safety Analysis, see also PRA
PSA Level 1	PSA of plant failures leading to the determination of core damage frequency.
PSA Level 2	PSA of containment response leading, together with Level 1 results, to the determination of containment release frequencies.
PSF	Performance Shaping Factors
RCPB	Reactor Coolant Pressure Boundary
RPV	Reactor Pressure Vessel
THERP	Technique for Human Error Rate Prediction
TTA	Tabular Task Analysis

A Practical Guide to HRA

1 INTRODUCTION

1.1 BACKGROUND

In nuclear power plants, humans have a major role in maintaining the plant in a safe state as well as, in certain scenarios, bringing the plant back to a safe state. Human reliability analysis (HRA) is an important tool for assessing the human contribution to failures, given the surrounding environment in which the humans operate. The EXAM-HRA project has during 2010-2015 been a Nordic, Swiss and German collaboration project, in which existing HRA applications have been assessed and compared in order to identify areas for plant improvement. The main goal of the project has been to produce a guideline for a state of the art HRA for PSA purposes, based on performed assessments, ensuring that plant specific properties are properly taken into account in the HRA.

The final reporting of the EXAM-HRA project provides an overview of the assessments done by developing a "Guidance on methods" document, see Figure 1. This is presented in this report in the form of a Practical Guide to HRA based on experience from the survey, evaluations in case studies and reassessments performed within this project.

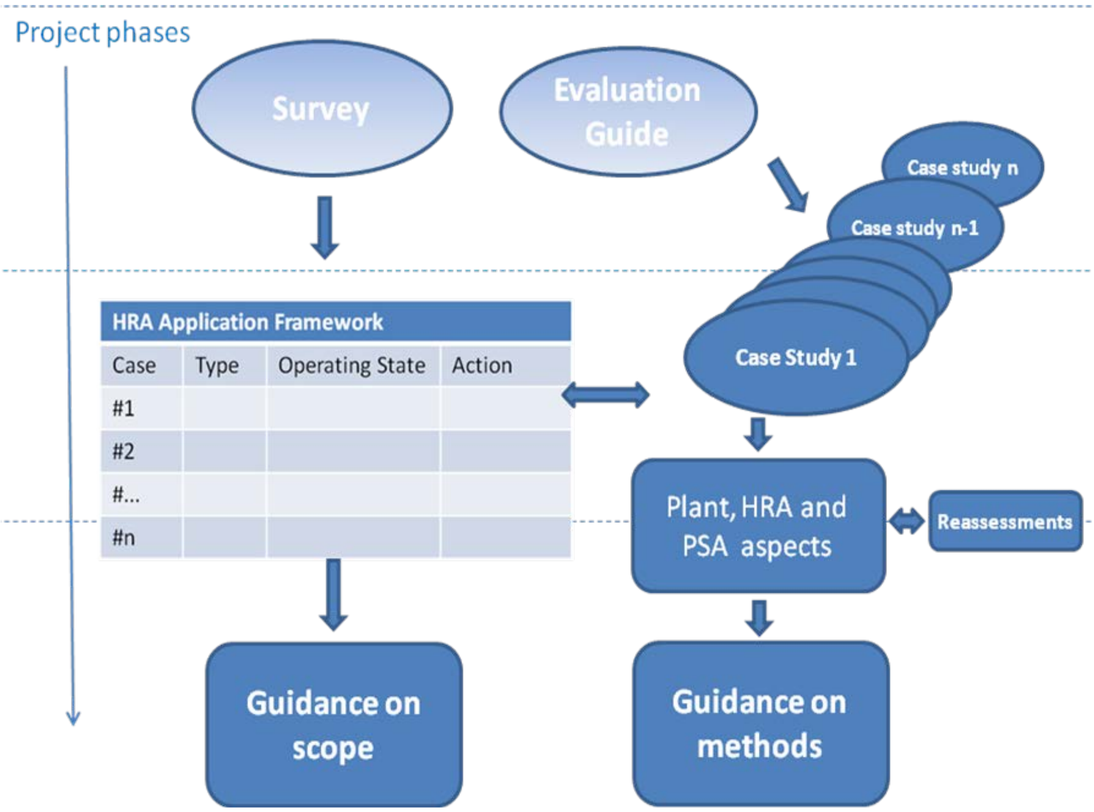

Figure 1 EXAM-HRA project overview

The human failure events (HFE) presented in the survey report and application framework has been used to develop a “Guidance on scope” document presented in the Application Guide [6].

The evaluation format developed within the EXAM-HRA project has been found useful and the assessments of actions performed in the case studies has resulted in findings regarding plant features as well as features of the HRA and PSA applications. These findings are an important basis for this practical guide and are further discussed in the project summary report [12].

1.2 OBJECTIVES

The guide covers a need for a short and practical guide to HRA. The practical guide shall support a PSA practitioner with recommendations on how to navigate through the HRA jungle by presenting a report easy to read with clearly expressed opinions.

The guide provides an overview of method and guidance available in literature and discusses considerations to take into account for the HRA attributes involved in an HRA application. Practical recommendations are presented together with actual examples from the case studies for each attribute to support the recommendations.

This guide presents no new methods or any new comparison of methods.

1.3 OUTLINE

The practical guide starts with an outlook on available methods and guidance documents to give reference to what can be seen as good practice when performing an HRA, see Chapter 2. Appendix A and B presents our summary of international guidance related to HRA.

The practical guidance is presented in Chapter 3-5. The attributes ("key words") presented in the Table 1 have been chosen to represent the HRA process.

Table 1 The attributes ("key words") to represent the HRA process.

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Chapter 3 “How to perform HRA” discuss each attribute in separate sections and each section discusses:

- **Consideration**, problem definition stemming from the assessments made of existing applications;
- **Recommendations** based on the evaluations, formulated with the objective to reduce variability; and
- Supporting **observations** from case studies of existing applications.

Appendix C provides methods to identify actions with possible dependencies. Appendix D provides a cross reference between this guide and the ASME requirements.

2 OUTLOOK ON METHODS AND GUIDANCE

An outlook on available methods and a summary of international guidance related to HRA is given in Appendix A and B. The summary of guidance is based on reference documents No. {2}, {3}, {5}, {6} and {7} of the documents listed in Table 5 in Appendix A.

The summary presented here is structured according to a set of HRA "key words" that represents important steps in the HRA process. The key words have been chosen by the EXAM-HRA project team of HRA/PSA practitioners/experts. It shall be noted that other key words might be chosen by other practitioner/experts and the selection as such do not claim to be an exhaustive list but rather a representation of important areas for an HRA based on the experience that has been collected during the EXAM-HRA project. In the same way the summary of international guidance do not claim to represent a complete summary of all available documents on HRA but rather represent a high level summary of what can be seen as good practice when performing an HRA.

The main purpose of this summary is to establish what can be viewed upon as a set of HRA quality criteria with the purpose of generating an HRA that is **transparent** and **adequate**, see Table 2. As mentioned in the Swiss HRA review guidance (document {6} in Table 6); an analysis is "transparent" if an external qualified person is able to reproduce the results, and "adequate" if such results reflect the plant-specific conditions related to safety. One can also add to this that it must be **reasonable** both in absolute and relative terms.

Selected key words can be categorized into **selection** and **quantification** of human errors. The attributes ("key words") presented in Table 1 in this report, have been chosen to represent the HRA process.

Table 2 Transparency, adequacy and reasonableness in HRA process

Selection of human errors	Process	Transparent
		Adequate
	Results	Reproducible
		Adequate/Reasonable
Quantification	Methodology	Transparent
		Adequate
	Implementation	Reproducible
		Adequate
	Results	Transparent
		Adequate/Reasonable

The literature refers to actions of Category A, B or C. A human failure event (HFE) in the context of PSA can be represented by a basic event, which stands for the failure of a task, which will lead to one, or even several, of the following consequences:

- Category A – Degradation (latent failures) or unavailability of a system/function required for mitigation,
- Category B – An initiating event,

- Category C – Failure to prevent/mitigate serious consequences of an ongoing accident sequence

Sometimes, an event is split into more than one task (diagnosis/decision making and implementation) that can be represented by a single basic event in the PSA.

3 RECOMMENDATIONS ON HOW TO PERFORM HRA

This section presents the HRA attributes organized in the same way as in Appendix B i.e. the attributes ("key words") presented in the Table 1 have been chosen to represent the HRA process.

When applicable the recommendations are based on the guidance presented in Appendix B.

3.1 SELECTION

3.1.1 IDENTIFICATION

Considerations

The identification of operator actions to be included in the PSA is generally poorly described across all the PSAs examined in the project. The identification is often performed and described as a part of the accident sequence and event tree description. The identification process can be improved quite significantly and it should at least be stated in the HRA documents how it has been made.

Within the EXAM-HRA project a survey of HFEs has been performed. The aim with the survey was to identify similar operator actions from HRAs of the participating plant which can be compared in the consecutive assessment of the chosen scenarios. Based on the overview generated in the survey and following case studies an application guide could be presented. The table of candidate HFEs presented in the survey report has been used to develop a guidance document on HRA application scope [6]. The objective of the application guide is to improve the consistency of in-depth HRA and HEP assessment by developing guidance on scope of HFEs to include in the HRA applications.

This is applied based on a check list to assess the reasoning for inclusion or exclusion of HFEs in the PSA models. By following the guide means are provided to get an understanding of how the HFE scope has been defined and how analysed operator actions have been chosen.

Recommendations

- Describe the identification process.
- The identification process should provide details on how specific operator actions are chosen.
- If details about the identification are given in other PSA documents, the HRA documentation should at least provide a summary of the identification process and give references to documents where further details can be found.
- The Application Guide [6] can be used as a tool for identification of candidate HFEs.
- Details should be described to justify why a particular HFE has not been included as well as to describe which HFE have been included.

Observation from case studies

Since the case studies that has been performed has mainly been focused on the HRA specific documents within the plants' PSA-documentation it is recognized that all inputs to the HRA have not been studied in the level of detail as the HRAs that has been performed. Nevertheless, a general conclusion form the HRA documentation is that it contains no or little information on how the identification of considered operator actions has been made.

3.1.2 THE SCREENING PROCESS

Considerations

The justification for choosing specific operator actions to be included in the PSA is often poorly described and to some extent also the reasoning for evaluating some actions in more detail than others. Comparing the screening processes for the different plants could give important insights for good practise with regard to what actions that should be included in the HRA to start with.

All participating plants have submitted information regarding operator actions and the scope of HRA applications in their plant specific PSA. An overview of actions is generated in the Project Survey [7] and case studies and this is summarized by the application context descriptions. The survey contains information which is used for grouping and selection of operator actions for further evaluation. The unit, basic event ID and basic event description is submitted for all operator actions where applicable.

The screening criteria used in the different PSAs for identification and the rationale for inclusion or exclusion of actions in the PSA models can be assessed.

Screening is sometimes not only concerned about a complete task, but also on parts of a task. In many cases, the implementation part of a task (execution) is considered negligible in comparison with diagnosis and decision making, if the complete task is implemented in the control room. In other cases, when the alarm pattern is very obvious, diagnosis and decision making may be considered negligible against implementation and possibly perception.

In some HRA applications the execution part is often ignored as it is assumed that the diagnosis and decision making is the main contributor to the HEP. In such cases it is however important to make sure that the available time is sufficient for the execution.

An operator action can be screened out for (at least) three reasons:

- The action is a substitute for an automatic activation, which is very reliable. Hence, there is no need to make the contribution even smaller. Hence screening out means treatment, as if the HFE had an HEP equal to 1.

- The action has very low probability of failure, and there is another basic event, possibly another HFE, against which the action is considered negligible. Hence, screening out means treatment, as if the HFE had an HEP equal to 0.
- The action has a very high probability of failure. Detailed analysis could result in an HEP only slightly smaller than omitting the action. Hence screening out means treatment, as if the HFE had an HEP equal to 1.

Recommendations

- The screening process should provide justification why specific operator actions are excluded as negligible or irrelevant in the PSA, see Table 3, if not included as relevant.
- General rules for screening criteria are presented in Appendix B that can be used. Especially the numerical criteria presented there should be considered when using numerical screening values that is used to determine if a more detailed analysis is needed based on risk importance.
- Neglecting the steps after diagnosis can strongly simplify the analysis; however, actions involving many steps with little time for recovery may obviously not have a negligible error probability compared to the error probability of the diagnosis part. If this is a deviation or limitation in the actual HRA assessment compared to the HRA method applied this should be stated and motivated/justified. A certain degree of conservatism can be taken into account in the assessment in order to not render an optimistic HEP due to this. Discuss criteria like: action in control room, lots of time and lots of recovery factors

The check list presented below, from the application guide [6], can be used for checking the rationale for inclusion or exclusion of actions in the PSA. This check list can be used initially as a part of the PSA model development or at a later stage as a part of a PSA model review.

Table 3 Check list for reasoning.

Why excluded?
Reasons relating to plant design. Action not possible in specific plant design. Action is possible, but time is too short. Action is possible, but it is too complex to benefit from.
Reasons relating to PSA concept. Action is not credited, because it is a backup to an automatic activation. Action is not credited, because it goes into an "and-gate" with some other event with low probability. Action is neglected, because it goes into an "or-gate" with some other event with large probability. Action is not credited, because it is known not to contribute to PSA results. Action is not included into the model to keep PSA logic simple. Action is beyond scope of PSA.
Reasons relating to methodological constraints. Action is not credited due to lack of written procedures. Action is not credited, because the method used is not applicable (e.g. too many skill based or knowledge based aspects). Action is not credited, because too little is known about the context, or the context is too variable to obtain a probability value. Action is not credited, because it would yield too small total HRA contribution to a SINGLE minimal cut set.
Administrative reasons. Action could have been credited, but there was lack of time. Action could have been credited, but there was lack of other resources.
None of the above; please specify.

Observations from case studies

– During the case study related to Category A – pre-initiators – it was noted how different testing of a system/function was treated in the aspect of latent failures. In some cases testing (before start-up) was used as a motive to screen out latent failures. In other cases, though it was recognised that testing is a barrier that will protect against latent failures, testing (at least during power conditions) as such can also introduce latent failures since the testing often means that some components, e.g. valves, may be aligned in a specific position in order to be able to complete the test without disturbing operation of the plant which introduces a possible failure to re-align to "normal" position. The conclusion from this is that it is important to carefully consider and motivate the screening criteria used.

– A common example of where recovery operator actions are screened out relates to internal flooding scenarios. An important factor for this seems to be the large number of analysed scenarios which would impose a significant work effort for the HRA. Instead of performing HRA for each scenario a conservative approach is used where manual isolation of the leak giving rise to the scenario is only taken into account for those scenarios that significantly contributes to the risk.

3.1.3 ERRORS OF COMMISSION

Considerations

Errors of commission (EOC) means the potential to make a situation more serious (e.g. keeping the coolant level low in a BWR to protect the steam pipes from water hammer, but by letting it drop too low uncovering the core erroneously leading to core damage. Or (the other way) increasing the level to protect the core, but erroneously overfeeding the pressure vessel, letting water pass through SRVs damaging them and convert what was a transient into a LOCA).

EOCs are strongly influenced by the way the alarm patterns and instruments of different scenarios may be nearly similar (e.g. wet well leak and service water leak in some plants). So, the control room team will diagnose the wrong initiating event, and decide for the wrong actions.

Second generation HRA try to incorporate in an HRA methodology the current understanding of why errors occur. Its underlying premise is that significant human errors occur as a result of a combination of influences associated with plant conditions and specific human-centred factors that trigger error mechanisms in the plant personnel. This premise requires the identification of these combinations of influences, called the error forcing contexts (EFC), and the assessment of their influence.

Recommendations

- Ideally, EOC should be taken into account and it shall at least be stated whether such actions have been identified or not.
- If EOC are not taken into account then try to justify how these HFE can be considered covered or negligible.
- Consider applying a second generation HRA method to identify EOC.
- Refer to Appendix B for further guidance on how to deal with EOCs.

Observations from case studies

As can be seen in Appendix B, EOCs are considered to mainly be a result of problems related to **plant information** or **procedures/training.** Two examples on measures that may prevent errors (including EOCs) are therefore given below.

– An example from the case studies related to **plant information** was the case when specific important alarms during a certain operating condition was more function based rather than symptom based, i.e. the alarm "malfunction of shutdown cooling" was introduced compared to the case when the operators need to diagnose the cause of alarms such as "high temperature in the condensation pool".

– An example from the case studies related to **procedures** was the case when it was noted that photographs was used in the procedures to help the operators to identify the correct equipment to manoeuvre for actions that are seldom performed. This is meant to assist the operator to locate the correct valves and thereby increasing the probability that the action will be successful.

3.2 DATA COLLECTION

The task related to data collection is an important step in the HRA process and provides vital input to the qualitative as well as quantitative analysis within the HRA. As a minimum the data collected should of course cover the information needed to estimate the HEP properly according to the chosen HRA method. It is however a general recommendation not to limit the information collected to the absolute minimum needed since this also will limit the usefulness of the HRA for other purposes than HEP estimation. In many cases the recommendations that are given within this section can cover several operator actions and it may be sufficient to collect the information once and then it can be applied during the assessment of several actions in the HRA process.

3.2.1 PLANT ORGANIZATION / MANAGEMENT

Considerations

Some new methods claim to measure the influence of management and organization on human performance. Obviously, in this case, aspects describing the organization with respect to human performance have to be collected. However, some general information on plant organization is useful for any HRA analysis. As this information is almost identical for any task to be analysed, this information is collected in a first step, which has sometimes been called “familiarizing with the plant”.

Recommendations

Information related to plant organization and management ("familiarization with plant") can be obtained by studying operating procedures, training manuals including simulator training exercises and from interviews of experienced shift leaders. With this general knowledge, the HRA analyst will be aided in estimation of things like how much time is realistically required to perform a specific task, and what level of personnel redundancy can be assumed for the single steps. Typically the information gathered during this step involves, among others, the issues given below.

- Number of people (manning) in the control room team and in the shift (typical and minimum numbers during day time and night time)
- General procedure for dealing with disturbances. Is there a procedure for post scram behaviour; is there a form/checklist listing available systems? Is there a guide to assess the initiating event?
- How is the control room team expected to organize their work?
- What external communication is likely? This normally is not necessary for the task, but will increase work load.
- Description of the control room. Such description can reduce the number of visits to the control room to a minimum, provided it contains information, where instruments and switches are located.
- Availability of human resources. Is it known, at what time after the incident additional resources become available?
- What is the general process for diagnosis and decision making?

Observations from case studies

- The case studies have revealed that even though diagnosis and decision making may be of focus during the HEP estimation the process for diagnosis and decision making is often scarcely described. This can for example relate to decision hierarchy, i.e. who makes the final decision.
- Another example from the case studies involve a potential Conflict of Interest (COI) related to activation of external water supply to the reactor coolant pressure boundary (RCPB) or the condensation pool, which would cause severe damage to the plant. However, if external water supply is not connected, a possible consequence is radioactive release. It was concluded in this case that clearly documented responsibilities regarding decision making as well as procedures explaining crucial precautionary measures, leaving out unnecessary measures, are likely to increase the probability of a successful action.

3.2.2 TASK SPECIFIC INFORMATION

Considerations

A specific task to be analysed should be described on a level of detail, as can be found in operating procedures and possibly in material on operator training. In order to find realistic assessments of the performance shaping factors, the analyst must know precisely, what has to be done, and how the operator is directed to the correct procedure that has to be used.

Recommendations

The task specific information must of course give the necessary information to be able to estimate the HEP value (based on PSF assessment or otherwise) but at the same time try to cover as many aspects as reasonably possible. Below, some examples of task specific information are given.

- How are indications presented to the operators, audible alarms or other?
- Based on the indications, are the operators required to interpret and diagnose the situation (symptom based) or will the indications immediately direct them to the type of problem that needs to be solved (function based)?
- What kind of procedural guidance is available for the operators?
- Where is the action performed?
- What kind of interface (HMI) is used, simple push button, within a relay cabinet, computerized interface, etc.?
- How can the operators verify that their actions have been successful and when?
- Any automatic plant response that is expected?
- Any automatic functions that has been disabled, intentionally or as a consequence of the initiating event or accident sequence.
- Any possible recovery actions that can be foreseen if the main task fails?

Observations from case studies

- From the case studies it has been noted that the same task in different plants can be performed in different places (in a panel in the MCR or in a relay cabinet close to the MCR) and it was also noted that the design of the relay cabinet differed which may be important for the HEP estimation.
- The case study related to performance of HRA for "actions without procedures" reveals the importance of not only identify if a, and what kind of, procedure that is available for the scenario, it is equally important to identify whether the procedure in question is able to aid the operators and to what extent the operators actually will rely on procedures for the action.

3.2.3 TASK CONTEXT

Considerations

Basically, the task context is given by the position of the task in the event tree in the PSA model. This means that it has to be evaluated which systems are operating and which are failed. From this, it can be concluded which other tasks have to be done before the task considered, or simultaneously with the latter.

Especially to assess performance factors like work load/stress and chances of faulty diagnosis, the analyst must be aware of what other work the control room team has to do. Part of this stems from the evaluation of plant organisation. In addition, it is important to know the context of the task.

Also, timing within the sequence is important. In early stages, the control room team will more or less work on their own. Later, there will be additional resources; on the other hand, the situation may become more complex, and threatening stress may evolve.

Recommendations

When describing task context it is important that the sequences that give rise to the need of the action is described in detail. Some examples of important information that need to be gathered are given below.

- What kind of initiating events lead to a demand for the task considered?
- How much time do the operators have for the action to be completed?
- If several initiating events give rise to the need for the same action, does this have an impact on available time?
- What is the known status of other functions/systems within the event tree?
- What kind of strategy will be used during the conditions at hand and what will be the main priority for the operators in short and long terms?

- Are there any conflicts of interest that may interfere in the decision making?
- In case of conflicts of interest, who will be responsible for final decision?

Since the purpose of the qualitative analysis, including the task context, is to form the basis for the quantitative assessment it has been concluded from performed case studies that the following aspects to be included are:

- The task context description must cover all the performance shaping factors considered in the HRA.
- In case that the HRA is related to hazards (internal/external fire/flooding and external events) it is important to include information in the task context if some aspects may change due to the hazard in question compared to other initiating events for which the action has been credited. This is always important when the same action is credited for several initiating events, not only in relation to hazards.
- In case the scenario considered is a "long term scenario" it is important that this is reflected within the task context, i.e. what impact will the "long term" aspect have on the context, e.g. is it likely that there will be a shift in crew during the scenario.

Observations from case studies

- It has been noted in the case studies that in some occasions the most conservative scenario is used when the available time for the action is defined, i.e. that gives the shortest time.
- It has also been observed in the case studies that possible negative aspects for long term scenarios (when time correlation curves may not be useful for HEP estimation) are not taken into account or even reflected upon. As an example of this it has been noted that the effects of shifting crew as a possible reason for operator failure is not considered. A positive effect of long time available is of course that it makes it possible for other personnel to assist. A critical reason for the error in such cases could be that some important information is missing for the new crew that may have a negative impact on the error probability, compared to the crew who worked on the problem from the beginning of the scenario. It shall be considered that the shift of crews is normally not part of the normal simulator training for the operators.

3.3 QUALITATIVE ANALYSIS

3.3.1 TASK ANALYSIS

Considerations

Task analysis in the context of HRA has two important aspects:

- It documents the qualitative information.
- It contains all information to assess/justify the performance shaping factors of the task considered.

Task analysis can be narrative or tabular. The precise structure depends on the method, and the method description should give detail on this. A possibility is to structure it according to the operating procedure, as a reviewer from the plant is familiar with these.

Recommendations

- The HRA method description should specify the structure of the task analysis.
- Consider structuring the task analysis in accordance with the procedures.
- Perform preliminary task analysis of the operating procedures before any talk-through with the plant personnel.
- Task analysis should qualitatively, for each step, check whether there are any human errors (omission or commission) that might have serious consequences.
- Task analysis should qualitatively, for each critical task, check, whether there is personnel redundancy.
- Task analysis should qualitatively, for each critical task, check whether there are recovery factors that permit corrections of steps which originally may have failed.

Observation from case studies

During one of the case studies a reassessment was made of a certain action using an alternative HRA method including a task analysis of all the steps the operators needed to go through according to the procedures. It was concluded from this exercise that the task analysis provided additional knowledge about the operator action assessed.

3.3.2 PERFORMANCE SHAPING FACTORS - ASSESSMENT

Considerations

There are some differences in how performance shaping factors (PSFs) are incorporated in the different HRAs. In some studies, performance shaping factors are used as calibration factors to adjust the HEP, which is primarily estimated based on available time for diagnosis and decision making. Also, the different studies included different PSFs. Some studies use the PSFs defined by Swain [9], whereas other studies have extended the PSFs and also include factors such as complexity and coordination of task. The use of additional performance shaping factors does give the potential of performing a more accurate estimation of the HEP.

Modern methods define taxonomy for tasks. For all methods, this appears to result in performance shaping factors to assess a task considered, where some of these factors are qualitative, others are quantitative. A method description should not only define these factors, but it should give precise guidance on how to assess them. For example the classification of stress into three categories (optimum, moderate, high) is of little use if there is no guidance describing what exactly is meant by these terms. Only, if the difference between moderate stress due to work load and high stress (feeling fear for the life) is known, the analyst can perform an assessment.

Results would be much more comparable if this guidance can be included in the method description.

Another example of a possible PSF that may lack guidance on how to incorporate in the HRA is conflict of interest (COI), which most likely is correlated with stress.

Another concern is related to choice of HRA method and corresponding PSFs. In many cases the HRA method to be used is more or less prescribed to the HRA analyst and by this also the PSFs. It should however be reflected upon if the chosen HRA method with its defined set of PSFs is able to capture the important aspects of the operator action to be analysed.

There are some differences in how PSFs are incorporated in the different HRAs. In some studies, performance shaping factors are used as calibration factors to adjust the HEP, which is primarily estimated based on available time for diagnosis and decision making. Also, the different studies included different PSFs. Some studies use the PSFs defined by Swain [9], whereas other studies have extended the PSFs and also include factors such as complexity and coordination of task. The use of additional performance shaping factors does give the potential of performing a more accurate estimation of the HEP.

Recommendations

- The set of PSF shall take into account, category of action, context, and where the action shall be performed.
- A thorough task analysis is a prerequisite for accurate estimation of the PSFs (and thereby accurate estimation of the HEP).
- In the selection of HRA method, consider to what extent its PSFs cover all important aspects related to the tasks of the HRA.
- A method description should specify the performance shaping factors.
- The HRA method description should give precise guidance on how to assess the performance shaping factors.
- Consider PSFs for the diagnosis and decision making process.
- Consider PSFs also for the execution of the action, actions involving many steps with little time for recovery may not have a negligible error probability, see also section 3.1.2 regarding screening of execution.
- Consider development of PSF (and/or its guidance) also for conflict of interest (for HRA method developers). This may especially be of importance in PSA Level 2 scenarios but it cannot be ruled out for other scenarios.

- When PSFs are used they must be orthogonal (independent) to each other as much as possible. If two or more PSFs measure the same phenomena, they will be correlated, and this phenomenon will be weighted stronger than another one covered by just one PSF.
- When several personnel categories are involved in a task, e.g. control room and maintenance, the PSF assessment should – as always – be made for each critical action. Here different personnel categories might be involved.
- In case the HRA is performed for an action during hazard conditions (internal/external fire/flooding and external events) it is important to consider if the PSFs used are capable of capturing the important aspects of the hazard in question compared to other initiating events for which the action has been credited. This is especially important when the same action is credited for several initiating events.

Observations from case studies

– A reoccurring finding relates to conflict of interest and how this can be modelled in a representative way as many of the cases assessed have an element of conflict of interest. However, this is never explicitly modelled. In some cases, the conflict of interest is implicitly included in the performance shaping factors but the underlying documentation used for the assessment do not give any guidance on how to specifically evaluate conflict of interests.

– During the case studies a comparison was made using two different HRA methodologies to assess one operator action (a reassessment). One result from the reassessment was a suggestion that the two methodologies to some extent could be combined. This means including additional performance shaping factors compared from one method, as well as performing a more explicit analysis of the execution steps according to the other method.

– In the case study related to control rod drive leakage during shutdown it was noted that only one plant had made the PSF grading for both maintenance and operating personnel.

3.4 QUANTIFICATION

3.4.1 METHODOLOGY

Considerations

A first requirement on a HRA method is that a method description exists, preferable in a form which is publicly available. During development of a method, it is clear, that not every detail is known. However, when a method is considered sufficiently mature to use for PSA, a full documentation should exist.

It has to be assumed, that the method under discussion is considered acceptable by the nuclear community, at least by the plant, and the PSA team, and reviewers/authorities. Given this, the purpose of a description is to present the method in a way that given identical information on the same task, two analysts using that description will perform similar analyses with identical results.

Every benchmark on HRA during the last thirty years has shown that apparently no such description exists. Given that analysts develop different levels of understanding of the tasks they analyse, they will make different decisions yielding different results. However, the idea of reproducibility of analysis should guide the definition of requirements for the HRA method description. Another aspect is transparency. If results cannot be reproducible according to the present state of the art, they should be at least transparent in the sense, that decisions of the analyst(s) are documented.

Although a description of the method will always depend on the method itself, some basic steps of analysis are required in more or less every method. They are used as a basis for the recommendations given below.

During the performed case studies it has been observed that THERP is the basis for most assessments, although in some cases screening methods or values are used. Local modifications of THERP are used in some HRAs where e.g. additional PSFs are included. These HRA applications are simplified variants of THERP, and are for the most parts based on a modified version of the THERP time correlation curve. Other methods follow THERP more strictly and incorporate the use of HRA trees for modelling the action steps including recoveries in detail.

In long term scenarios, time correlation curves are not useful for estimating the HEP. Instead limit values are applied, although it is not certain these values are more accurate. Another observation related to long term scenarios is the effects of shifting crew, see task context in section 3.2.3.

The inclusion of recovery in the HRA is also dependent on the mission time. Generally a recovery action should be taken into account if there is additional time during the human failure event to notice an error and correct it. In long term scenarios there is a higher likelihood of having ‘extra’ time for recovery. However, it was noticed that among the HRA applications some are not considering to include recovery possibilities even for long term actions.

Recommendations

- The method description should provide details, how probability values are obtained given specifics on how to interpret the information on the task. This information can be given in terms of correlation or tables.
- Specify what PSFs that are taken into account
- Specify what information is needed to apply the methodology including the PSFs for quantification.
- Objectivity would increase if using as little expert estimate as possible.
- Completeness would increase by performing detailed analysis of all steps required, in order to identify steps with no recovery.

- Consistency can be increased by including additional and more precise guidance on assessment of PSFs.
- Describe how to document the application to allow for reproducibility of the analysis and to make the application transparent.
- In case the HRA methodology most commonly used within a certain plant's PSA is not well suited for a specific action/scenario it is likely that it is better to use another methodology compared to making adaptations to the existing one and try to apply it outside its intended scope.

Observations from case studies

– A finding from the case studies related to HRA methodology is that simplified HRA applications sometimes give less conservative results than more detailed applications. This finding could be due to a number of reasons. One reason is related to the assumption not to include the action part in the assessment, another to how the performance shaping factors are interpreted. However, it could also be that the methods used, which are often applied in a general manner, are in fact not suitable for a specific case. This is of importance since one main justification for using simplified methods is that it would result in conservative results. The issue of need for questioning the method validity indeed applies for both simplified and more detailed methods. In fact, more detailed methods tend to give more conservative, not necessarily more accurate, results. This contradicts the intentions of ensuring more conservative results by using simplified methods. Consequently, the use and application of methods do have a potential impact on the results; regardless of on which level of detail it is performed.

– During the case study related to manual isolation of leaks during internal flooding it was noted that one plant had used a separate HRA methodology developed by EPRI [11]. The reason for this was the fact that the actions to isolate a pipe break were not called out explicitly by the procedures and therefore the HRA methodology applied for other internal events could not be applied.

3.4.2 PERFORMANCE SHAPING FACTORS – CALCULATION

Considerations

Depending on what PSFs that are taken into account the method/tool being used should provide definitions and guidance for assessing PSFs qualitatively (e.g., “good,” “adequate,” “poor”). The guidance for assessing the PSFs must be sufficient to ensure consistency of the results.

If the performance shaping factors are not given the correct value or if they are misinterpreted, there is a risk of the HEP becoming more inaccurate. Consequently, performance shaping factors can increase the quality of the HEP estimation although, in order for it to be achieved, a thorough task analysis is a prerequisite. Another issue related to the PSFs is that they may mainly be defined having the diagnosis and decision making process in mind. It could however be occasions where there is a request to interpret

PSFs also for the execution, although for this the existing PSFs may not be suited. Consequently, there may be a need for development of PSFs also for the execution of the action, especially considering the finding from the case studies that the execution part of the HRA often should be paid more attention.

Recommendations

- The method/tool being used should provide definitions and guidance for assessing PSFs quantitatively to interpret the results into a quantified HEP
- Provide examples on how to interpret the qualitative rating of the PSFs into quantified PSFs
- Extensive guidance for assessing PSFs could improve the consistency of the results, The method description shall include:
    - The set of PSFs used
    - Definitions of PSFs
    - Guidance to evaluate PSF weights
    - PSF weight range
- When several personnel categories are involved in a task, e.g. control room and maintenance, the PSF assessment should be made for all the different personnel categories. This can for example be made by defining different HFEs for each personnel category.
- In the case the HRA is performed for an action during hazard (internal/external fire/flooding and external events) conditions it is important to consider if the PSFs used are capable of capturing the important aspects of the hazard in question compared to other initiating events for which the action has been credited. This is especially important when the same action is credited for several initiating events.

Observations from case studies

– In one of the studied HRA methods the performance shaping factors have a range of 0.2 … 5. This is used as a multiplier on the base HEP. This means that the PSFs has the same effect on the total HEP. The guidance to use the performance shaping factors gives a connection between each PSF weight and a short qualitative description what that weight should mean in terms of the scenario. Between the Nordic plants several scenarios might have a total similar effect of PSFs, but the individual PSFs have differences. Especially the PSF that describes "stress" might be difficult to evaluate. It can be noted, however, that the individual values of the PSFs do not matter from HEP point of view, as long as the composite effect of the PSFs is roughly correct.

– The scales for assessing the PSFs differ between HRA methodologies. In some cases a numerical scale (1-5) with supplementary descriptions on the meaning of each grade is used, in other cases a more qualitative scale is used (very inadequate – very supportive).

– In the case study related to control rod drive leakage during shutdown it was noted that only one plant had made the PSF grading for both maintenance and operating personnel.

3.4.3 DEPENDENCIES

Considerations

A number of HFE dependencies are defined in the guidance documents that require to be systematically considered.

Recommendations

- In order to evaluate if there are several basic events representing human actions related to one scenario, the cutset list can be used as a tool to identify possible candidates for dependency analysis with respect to HRA.
- Several methods can be used to identify HFE treated as redundant and (possibly inadvertently) independent in the cutset list. Appendix C present examples based on the RiskSpectrum® PSA software.
- Assess possible cross system dependencies for Category A actions due to common procedures.
- Assess possible dependencies for Category B and C actions.
- When calculating a final HEP value for any category of operator action (A, B or C), dependencies between the failure events and credited recoveries must be taken into account.

Observations from case studies

– As has been stated several times before in the provided examples a reoccurring finding in the case studies relates to conflict of interest and how this can be modelled in a representative way. It has been noted that several of the cases assessed have an element of conflict of interest but this is rarely explicitly modelled. For some scenarios, especially in PSA Level 2, conflict of interest is likely to have a considerable contribution to the failure probability and this aspect consequently needs to be well understood and properly incorporated in the HRA. In some cases, the conflict of interest is implicitly included in the performance shaping factors but the underlying documentation used for the assessment do not give any guidance on how to specifically value conflict of interests.

– During the case study related to initiating event frequency (Category B) for control rod drive leakage during shutdown it was noted that the final HEP values used as initiating event frequency differed by several orders of magnitude. For some plants the resulting value seemed to be too small to be credible. One reason for this is that failure events and their possible recoveries have been treated as independent and no consideration was taken to uncertainties. Another reason is that recoveries may not have been considered at all for some plants. As an alternative to perform a HRA it was suggested if it should not have been possible to use historical data instead for this initiating event frequency.

3.4.4 UNCERTAINTIES

Considerations

Consideration of uncertainties is a requirement for PSA. As HRA results are input for PSA, uncertainties of HRA results have to be part of a model and its description.

The following cases of uncertainties exist in the context of HRA:

- First, values used stem from experiments with sufficient data. In this case, the main question is, whether the scenario in the experiment fits the reality of the task which the value is used for. Most of experimental data stems from THERP. Swain quotes experiments, where the subjects whom the experiment have been conducted on have been students (and not well educated employees of a nuclear power plant). In order to quantify the difference between threatening stress and excessive work load, he refers to research comparing U.S. air force pilots in exercise with those in realistic fight situations in Vietnam War. It was the best data available according to his opinion. However, there may be a difference between flying a military airplane and mitigating an unknown nuclear accident. Statistical uncertainty due to lack of evidence appears negligible in this context.
- The second case is data stemming from expert judgement. In this case, the main question is, whether the expert had in mind the reality of the task which the value is used for.

In both cases, uncertainty is clearly of epistemic type. Even, if the values have an experimental background, the uncertainty is expert opinion. The lognormal distribution, which is characterized by a median value and an error factor, is normally used to express this type of uncertainty.

Within the case study related to "actions without procedures" a discussion is made whether an action is skill based or knowledge based. For a skill based action the HRA analyst may come to the conclusion that such can be successful provided that it has been trained thoroughly even if the time for the action is limited. Another alternative is, for actions that are not supported by procedures, that it is judged to be knowledge based, i.e. will not depend on regularly learned skills, but on common and engineering judgment. Such judgment may be successful, too, but it will always require time. Given such a scenario, there will be large uncertainties dependent on personal properties of those involved, and, if analysis is attempted at all, it will be more an expert guess than an expert judgment. In such case, writing a procedure if none exists is the only solution to obtain a high probability of success.

Another concern is related to the use of median values. If an HRA method uses the median values in the THERP tables as point values, this will result in a simple method which normally requires just a spread sheet to calculate the result. In this case mean values must be used as point values other vice the results will become optimistic.

This can be justified by the following reflection: The lognormal distribution has median value $M = exp(\mu)$, and expected Value $E = exp(\mu + \sigma^2/2)$, where μ and σ are the parameters of the underlying normal distribution of the logarithm of the random variable. Hence, the expected value is by a factor $exp(\sigma^2/2)$ larger than the median value provided in the THERP tables. Now, σ can be obtained from the uncertainty factor k, which is also provided in the THERP tables as $\sigma = ln(k)/1.645$. If the ration E/M is plotted against k, this leads to the following figure.

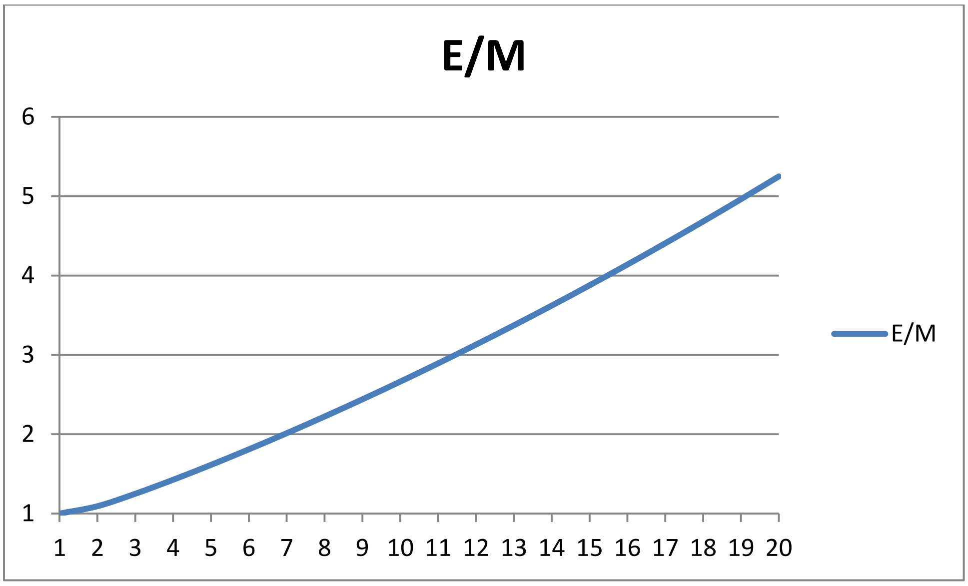

Figure 2 The lognormal distribution E/M ratio

If the uncertainty factor is 20, the expected value will be more than five times larger than the median value. Of course, positive PSFs will decrease the value, but they just constitute one of two factors in a product. If the other factor is too small, the result of the product will also be too small.

Recommendations

- The method description should provide details on uncertainty assessment.
- Aleatoric (parametric) and epistemic (modelling) uncertainties should be addressed and the uncertainty assessment shall be consistent with the quantification method
- When calculating a final HEP value for any category of operator action (A, B or C), uncertainties within the failure probabilities for failure events and recoveries should be accounted for. As a minimum, the uncertainties shall be addressed at least for the significant HEPs to be able to understand and address those in order to make appropriate risk-related decisions.
- In order to be able to assess the uncertainties for an action it can be good to define whether an action is rule, skill or knowledge based.

Observations from case studies

Additional sources of uncertainty between plants appear to be:

– Different assessment of recovery.

– Different assessment of dependency

A conservative approach may be simple, but it will reduce the capability of HRA to reflect properties of the plant.

3.4.5 RECOVERIES

Considerations

Depending on level of stress and other attributes of the working conditions, human errors occur with rates roughly between 1E-2 and 1E-3 per step. As there are sometimes some dozens of steps to do, this leads to large probabilities of failure for the complete task. Although the figures above are realistic (or even optimistic) failures probabilities for complete tasks are much lower. The reason for this is recovery. Recovery is the possibility to correct an error before severe consequences develop. An analysis of recovery is a precondition for a realistic assessment. The following recovery mechanisms are known.

<u>1) Recovery by self-checking</u>

This mechanism is not modelled explicitly in THERP. But it is modelled in CBDT. In THERP, a distinction is made between the availability of written procedures and check lists, or oral instructions. This may implicitly model self-checking.

<u>2) Recovery by personnel redundancy</u>

In the control room, there is at least one shift leader and a deputy. At least one of them shall follow the progress of work, and may notice errors of operators and interfere. Task analysis should reveal, whether there is sufficient time for the leader to act as personnel redundancy. It must be noted, that the check by personnel redundancy is generally not independent. The coupling model, which stems from THERP but is also used in other approaches (e.g. SPAR-H, NUREG/CR-6883), accounts for this. Task analysis may show, that in later phases, the shift may receive help from a shift technical advisor, who acts as an additional personnel redundancy.

<u>3) Recovery by annunciated cues</u>

Many important measurements have more than one alarm for exceeding the correct range. As an example the level in the reactor vessel of a BWR can be connected to four or five alarms, if it becomes too low, or too high. Should a step be omitted which had the intention to increase the water level, the level will continue to decrease. If this happens reasonably slow, the additional acoustic alarm will be a strong indication (a cue), that something went wrong. If there is a sufficient time buffer, the error can be corrected. Task analysis should reveal, whether the timing criterion is fulfilled. If there is sufficient time, this type of recovery is independent from the original erroneous step.

<u>4) Recovery by non-annunciated cues.</u>

In some cases, procedures will contain checks for success of performed prior steps. If e.g. a pump has been switched on, there may be a check for the flow produced by the pump, or for the electric current it consumes. If this check succeeds, it will act as a recovery step. In other cases, there may be a rule, which asks one member of the control room team to take repeated readings of key values and to announce them loudly. This may also act as recovery. Information of this type is acquired during familiarization with the plant. Task analysis will have to assess, whether there is sufficient time and whether there are sufficient resources to take credit from this type of recovery.

Recommendations

- The minimum joint failure probability following modelling of a recovery action(s) must be checked.
- An explicit modelling of recovery in task analysis acts as a check for the procedures. Should there be steps with no recovery, this may be an indication to modify the procedure accordingly.
- When recoveries are specified it is important to give a thorough description of the context and accident sequence in order to be able to motivate and justify the recoveries modelled.
- When recoveries are assessed it is important to include enough grace time for the operators to be able to decide upon and execute any recovery.
- Recovery factors should already be assessed in the qualitative part of the HRA, such as the task analysis.

Observations from case studies

– It has been noted in the case studies that treatment of recoveries differs among the studied PSAs, which may of course be due to differences in plant design. An example of such difference is related to loss of residual heat removal function. In one PSA only, restart of the original residual heat removal function is considered. In the other PSAs, recoveries using alternative residual heat removal functionalities are modelled. Other examples are found where recoveries are explicitly modelled in some case, but not in others.

– In the case study related to heavy load drop (drop of RPV head) it was noted that the final initiating event frequency differed with several orders of magnitude between the plants. It was concluded that this partly is due to the fact that recoveries was not always considered even though this didn't explain the whole difference.

3.4.6 MINIMUM BELIEVABLE RESULTS

Considerations

The reasonableness of the estimated HEPs should be checked both in relative terms and absolute terms. Potential dependencies between HFEs should be considered, see Appendix B and section 3.4.3. Even though the heading of this section indicates that this mainly applies to low HEP values (since they may yield optimistic PSA results) checking the reasonableness of derived values actually applies to all HEP values, see section 3.5.1 for more details.

Recommendations

- The lowest reasonable HEP must be considered and too low HEPs are not accepted. Such low value shall be replaced by the lowest reasonable HEP. Another way of phrasing this is that when calculating a final HEP value for any category of operator action (A, B or C), it should be checked if a low HEP is too low in order to be reasonable.
- The minimum joint failure probability of actions which act as redundancies (are in the same minimal cut set) shall be checked and shall meet a Human Performance Limiting Values (HPLVs).
- Whenever a low HEP value is reached during the assessment aspects such as if there are any conflict of interest should be considered, i.e. is the low HEP value "realistic" or are there any aspects that have not been taken into account.
- Another aspect that needs to be reflected upon whenever a low HEP value is derived is if the applied HRA methodology is capable of capturing a "realistic" HEP value for the action in question.

Observations from case studies

– In several of the case studies it has been noted that operator actions may have conflict of interest (COI) as an element that need to be assessed in the HRA. An example of such action is related to activation of external water supply to the reactor coolant pressure boundary (RCPB) or the condensation pool, which would cause severe damage to the plant. However, if external water supply is not connected, a possible consequence is radioactive release. If the COI element is not taken into account the quantified HEP value may be optimistic.

– During the case studies related to initiating event frequency (Category B) for control rod drive leakage during shutdown and drop of RPV head it was noted that the final HEP values used as initiating event frequency differed by several orders of magnitude. For some plants the resulting value seemed to be too small to be credible. One reason for this is that failure events and their possible recoveries have been treated as independent and no consideration was taken to uncertainties. Another reason is that recoveries may not have been considered at all for some plants.

3.4.7 ACTIONS WITHOUT PROCEDURES

Considerations

According to Rasmussen’s model [10], three types of human behaviour can be assumed:

- Skill based – highly practised activities that can be performed with little apparent thought,
- Rule based – performance of less familiar tasks but within the normal experience and ability of the particular individual,

- Knowledge based – performance of novel tasks where familiar patterns and rules cannot be applied directly. A high level of cognitive processing is necessary.

It is usually meaningful and quite straight forward to write procedures for rule based actions. Therefore actions without procedures tend to be skill or knowledge based. Although e.g. identifying a leakage may not be a simple task, it may be classified as skill based, if it is trained thoroughly and the training is assumed to be the basis for a successful action. If there is little time available, the task can only be performed successfully with a reasonable probability if it is skill based. However, this requires training of the task at the plant concerned.

On the other hand, if actions have not been supplied with procedures, because there may be strong differences in the context, which influence the exact content of the actions, such an action is knowledge based. It will not depend on regularly learned skills, but on common sense and engineering judgment, which require time. There will be large uncertainties in the outcome of the action dependent on personal properties of those involved. In such case, writing a procedure, if possible, is the only solution to obtain a high probability of success.

Recommendations

Actions without procedures can be taken into account using three basic approaches:

- A critical scenario where no proper procedure exists is identified, which leads to plant modification or preparation of an instruction. Temporarily, the PSA may include an action for which a high human error probability (HEP) value is used (e.g. HEP = 1).
- The scenario is complex and its risk importance is a controversial issue. Non-existence of the procedure is due to the difficultness to prepare an instruction for the scenario. Nevertheless, an operator action is included in PSA, and a high HEP value is used.
- The procedure is not really necessary for the action so that the non-existence of procedure is not an issue for HRA.

The most suitable approach depends on the context and is also partly a matter of taste of the analyst(s).

Observations from case studies

- Two methods for explicitly taking actions without procedures into account were found in the case studies:
  - Enhanced Bayesian THERP: A PSF called “Quality and importance of procedures” is included, see Table 4. The method does not as such limit the HEP values derived.
  - Method by EPRI [11]: A quantification tree exists for determining the HEP for actions without procedures including following variables; **time** available for action, relative **complexity** of action, availability of **training or practice** for action, nature of **environment** for work area. The possible

HEPs for the different variable combinations range from 0.01 to 1.

– If a risk significant action without procedures is identified, an alternative approach to those in the above recommendations is to ease the task by placing an operator by the equipment in question, ready to perform the action if needed. This implies that there is some critical and limited time window when the need can be called upon. An example is found in the case studies where a dedicated person trained to close the containment airlock during critical stages of the maintenance work was positioned outside the air lock.

Table 4 The PSF for "Quality and importance of procedures" in Enhanced Bayesian THERP.

Scale	**PSF: Quality and importance of procedures**
	Are there procedures? Are they needed? Do they give support?
5	No instructions or misleading instructions, instructions would be needed
2	Instructions are important but they are imperfect
1	Instructions play no major role in the situation
1/2	Good instructions, applicable for the situation and they support well the selection of correct actions
1/5	Very good instructions, operators should not make any mistake

3.4.8 HRA FOR HAZARDS

Considerations

Hazards (internal/external fire/flooding and external events, e.g. seismic events) are events that are quite specific in their nature, especially in the sense that they often affect large portions of a plant or even an entire site. Due to this it is challenging for an HRA analyst to estimate the likelihood for success of operator actions and there is not much detailed guidance to rely on (except for internal fire and flooding), in some cases specific HRA methods have been developed and used for specific hazards such as seismic events. The reason for applying a different HRA method is of course to be able to take into account the hazard specific conditions for credited manual actions.

Furthermore it is quite common that the hazard PSA is integrated with the PSA for internal initiating events which in turn means that it is not unlikely that the same manual action is called upon both for internal initiating events and for hazards. As is being stated in the summary of guidance in Appendix B there might be several hazard specific conditions that need to be considered. Common practise is to take into account whether the place where the action is to be performed is accessible or not and the impact that the hazard will have on technical functions are handled by the logics in the fault trees an event trees.

Recommendations

In case that the HRA is related to hazards (internal/external fire/flooding and external events) it is important to take following into account, especially when the same manual action is credited for several initiating events:

- Include information in the task context if some aspects may change due to the hazard in question compared to other initiating events for which the action has been credited.
- Consider if the PSFs used are capable of capturing the important aspects of the hazard in question compared to other initiating events for which the action has been credited.
    - The list of additional conditions given in Appendix B, Table 13, can be used as a checklist.
    - In case the used PSFs are judged not to be able to capture hazard specific aspects additional PSFs should be considered. Alternatively, use another HRA method for hazard conditions.

In case the hazard specific conditions cannot be taken into account, a conservative approach should be applied, for instance by modelling the impact of the hazard on such high level in the fault trees that an entire system or sub-division is failed regardless of successful manual actions. If this yields to conservative results, the hazard specific cutset list should be examined so that manual actions that have been credited are identified and documented. It is also recommended to include a motive for why it can be considered reasonable to take credit for those actions.

Observations from case studies

– Different treatment of PSFs for hazard conditions compared to internal initiating event conditions was seen in the case related to HRA for hazards. Some plants responded that no PSFs needed to be treated differently for hazards compared to internal initiating events while others responded that PSFs such as workload, time pressure and stress could be affected.

– All plants that was included in the case study related to HRA for hazards (internal/external fire/flooding and external events) had made assessments on the HEP values derived from the internal events HRA to consider hazard aspects. The overall strategies applied can be summarized as follows:

- In all PSAs the number one priority is to determine if the place where the operator actions is to be performed is accessible or not:
    - If OK; then HEP from internal events are used. If not OK, then HEP = 1.0 is used;
- In some cases the PSFs for the HEP is adjusted (stress, time available, work load) to adjust the HEP;
- One approach was to increase HEP value for internal events with a factor of 10, or set to 0.1 (highest value used). This approach is mainly used when it is difficult to determine exactly how the operator action is affected by the hazard in question, for instance when the modelling technique used makes it difficult to determine exactly where the action takes place.

3.5 VERIFICATION AND VALIDATION

3.5.1 REASONABLENESS

Considerations

A general conclusion from the case studies is that there are major differences between the plants in terms of level of detail of included operator actions as well as significance of the manual actions. A specific example of this is related to the internal flooding analyses even though the conclusion in general is valid for the whole PSA. Also, the number of manual actions varies a lot between the plants.

Another concern from the case studies is that in some cases the final HEP values are very low which may not be realistic or reasonable which raises the question if it is checked for reasonableness is anything that is part of common HRA practise, e.g. comparison with historical data when such is available.

Another observation related to the case study on control rod drive leakage during shutdown relate to the differences between what kind of initiating events and recoveries the different plants have included. In the case study it is concluded that most likely, this is due to the fact that different analysts have performed the PSA/HRA. The Application Guide [6] can act as a checklist on whether the HFEs included in a PSA match those that are included in other PSAs for similar plants.

Recommendations

HRA results should be reasonable relative to other events in the PSA as well as in absolute terms. Considerations regarding reasonableness are given in Appendix B. It could be achieved by:

- Comparison with actual plant history
- Benchmarking with HRAs for other plants, see for example the Application Guide [6].
- Sufficient qualitative understanding of the manual actions

Approaches to ensure that unrealistically low HEP values are not used in the PSA are discussed in Appendix B. There is one important recommendation:

- The total combined probability of all human failure events in the same cut set should generally not be below the range of 1E-4 to 1E-5. Lower HEP values could be used in certain cases, but should then be clearly discussed and motivated.

Observations from case studies

– A conclusion from the case study on control rod drive leakage during shutdown is that the HRA results vary much between the plants. This can hardly be justified by actual plant differences. It might be that existing HRA methods are less precise concerning initiators (human erroneous actions of Category B) in comparison with post initiators (human erroneous actions of Category C).

– In the case study related to heavy load drop (drop of RPV head) it was noted that the final initiating event frequency differed with several orders of magnitude between the plants. A comparison with historical data may be possible for an action this frequent.

3.5.2 TRANSPARENCY

Considerations

Even though most HRA assessments rely on a specific HRA method that is supported by a method description it is not uncommon that the HRA method description lack detailed guidance on how to apply the HRA methodology which often will result in that the analysis as such will be very much dependent on the analyst(s) and the different assumptions made by him/her. This and other factors, such as different limitations in scope, budget and time for the analysis, often result in an analysis that will not be as transparent as can be desired and as a result it will be difficult for another person to repeat or even understand the results.

It is furthermore not uncommon that an HRA is limited or simplified in different ways so that it does not follow the methodology as intended, this may also be for the reasons given above. Such limitations or simplifications are also reasons why the HRA can lack in transparency compared to the "ideal" HRA.

Recommendations

An analysis is transparent if an external qualified person is able to reproduce the analysis results. Considerations regarding transparency are given in Appendix B. There are three main recommendations:

- To clearly present the bases for inclusion or exclusion of manual actions in the HRA, i.e. to show why some manual actions are considered and others screened out.
- To show how the HRA method generates HEP values and how this is represented in the PSA model.
- To clearly specify any deviations, limitations/simplifications and assumptions made during the HRA.

In order to fulfil the last two recommendations it is necessary to clearly document the different steps that operators (or others) need to perform in order to complete a task and especially what can go wrong, e.g. in a task analysis. It is also important to document how different PSFs and other factors have been assessed and why they have been given a certain grading that will influence the resulting HEP.

Observations from case studies

– In one of the case studies, a reassessment was made of a specific action using an alternative HRA method. During the reassessment a more detailed study was made of the procedure for the actions in question. The procedure was in the reassessment presented as a tabular task analysis where it was documented what steps in the procedure that could result in failure of the task if performed incorrect. It was concluded that this task analysis gave an increased understanding of the HRA and therefore also increased transparency.

– An example of an analysis that was not transparent was isolation of leaks in the internal flooding PSA. A methodology was presented where it was stated that several factors (including available time) needed to be taken into account during the assessment. In the actual analysis though, it appeared that a simplified approach was used where a success probability of 0.99 (HEP = 0.01) was used for manual isolation of a leak if the available time is sufficient (1.5 h). Even though the approach applied is straightforward and transparent it was not clear how other factors (e.g. information presented to operators, identification of necessary actions, risk for misinterpretation of information, etc.) dictated by the methodology had been taken into account.

3.5.3 ADEQUACY

Considerations

HRA methods can be referred to as techniques that are used in order to assess human reliability measures when no or little historical data is available. A result from this "definition" is that it is difficult to check whether the HRA gives adequate HEP values or not.

A general rule can therefore be that whenever plant history data is available a more statistical approach should be preferred instead of, or in combination with, performing an HRA. However, as a statistical approach relies on historical data it can be a challenge to estimate the likelihood of success for future conditions.

Recommendations

An analysis is “adequate” if the results reflect the plant specific conditions related to safety. Considerations regarding adequacy are given in Appendix B. It leads to the following recommendations:

- The HRA should be performed in such a manner that it allows for identification and justification of plant improvements.
- A sufficient set of human errors should be addressed (for Category A, B and C).
- Plant specific and task specific inputs should be sufficiently addressed.
- The HRA method should be used within its scope of application.
- Dependencies between human errors, even between systems if needed, should be addressed.
- HEP uncertainties should be addressed adequately in order to make appropriate risk-related decisions.
- When possible, the HRA result should be checked against plant historical data or HRAs performed for similar plants.

Observation from case studies

An observation related to the case study on control rod drive leakage during shutdown relate to the differences between what kind of initiating events and recoveries the different plants have included. In the case study it is concluded that most likely, this is due to the fact that different analysts have performed the PSA/HRA.

4 DOCUMENTATION

4.1 GENERAL

Methods tend not to provide details on documentation. It is however important that the documentation supports transparency.

HRA is an important part of PSA and the outcome of an HRA may heavily affect the PSA results. It is important to consider that in HRA, qualitative information is as important as quantitative results and HRA results should also be used as a tool for recommendations for plant improvements. This leads to three general recommendations on documentation:

- When HRA is used for PSA purposes, it should be a natural part of the PSA documentation. The HRA should be updated in the same manner as other parts of the PSA in order to reflect actual plant status as well as new knowledge.
- The structure of HRA documentation shall be defined clearly. It is suggested that a HRA documentation plan is included as a part of the HRA methodology presentation. Issues to conceder are:
    - HRA methodology should be presented in one section or report in the PSA documentation.
    - It is important to reflect over the strengths and weaknesses of the chosen HRA method.
    - The analyses themselves should be presented in other sections or reports in the PSA documentation, e.g. one for each operating mode, which in turn could be divided based of category of manual action: pre-initiator (Category A), initiator (Category B) and post- initiator (Category C).
    - Sometimes pieces of HRA can be found in parts of the PSA documentation not specifically dealing with HRA, e.g. when calculating initiating event frequencies not directly connected to HRA. This could be acceptable, but it is important to clearly mention this in the HRA documents, to achieve traceability.
- Identification of actions required for given scenarios are performed in the context of accident sequence analysis/description of event trees. Cross references between this part and the actual HRA would be useful.

4.2 SCENARIO DESCRIPTIONS

The HRA scenario descriptions should give an understanding of when and why manual actions are required. It should also give information regarding where the actions are performed (e.g. main control room or locally), how the specific scenario will be detected, if an action is easy or complex to perform, if there are any operating procedures available and if there are specific circumstances regarding the action to be performed.

Recommendations are as follows:

- It is crucial to document why certain manual actions are screened out in the HRA.

Task analyses are needed to understand the scenarios and its contexts:

- It is essential to describe after which initiating event a manual action is credited, the overall steps of the action and the measures needed to be performed at each step.

Understanding dependencies between operator actions is essential:

- It should be documented whether any complementary manual actions exist in the scenario and if so the relation between the actions.

4.3 QUANTIFICATION

The quantified results of an HRA, the HEPs, are used in PSA models, most commonly as basic event failure probabilities. To achieve traceability the following recommendations should be met:

- It is vital to document the connection between scenario descriptions and HEP calculations, i.e. the available time for an operator action and performance shaping factors (PSFs) used for HEP calculation should match the scenario description, regardless of which HRA method being used.
- It should be documented how the PSFs are obtained.
- Uncertainty in the HRA results should be documented.

5 HRA ANALYST TEAM

The HRA approach requires significant amount of skill and judgment and should not be implemented without HRA experts. Below are the necessary characteristics when composing the PSA/HRA analyst team presented.

Competence needed within PSA/HRA team

Apart from an HRA practitioner/expert, preferably someone with good knowledge of the PSA, additional support is needed from a human factors specialist to support the HRA practitioner/expert. The disciplines needed in the PSA/HRA team are:

- PSA modellers
- HRA practitioners/expert (someone trained or experienced in HRA)
- Human factors specialist

The HRA practitioner/expert shall provide bridge between the PSA specialist and the team support. The human factor specialist shall support the HRA in doing the data collection and task analysis. Without human factors specialists, there is a tendency not to consult plant personnel/instructors, but to rely more on plant documentation.

While it is hard (or impossible) to find a single person representing all three disciplines, there might be possible to combine either PSA/HRA or HRA/HF in one person. Thus it is the understanding that the human factors specialist should have a more active role than just being supportive on request.

In order to get an overall understanding of the scenario context you will need input from different approaches.

- Thermal-hydraulics analysts
- Operations, training and maintenance personnel with experience in plant behaviour and conditions
- Task analysis
- Deterministic analysis

Review/Verification

Using a simulator as verification is a good way to find out how the team cooperates, to what extent leader and/or deputy leader can act as personal redundancies and what other duties might exist. However, using simulators to verify numbers will always be difficult and is not applicable on every scenario.

A simulator is also useful to limit visits to the control room. Typical positions of the operators, location of instruments and actuators and alike can be found there. Possible review/verification activities can include:

- Walk downs/field observations
- Simulation exercises
- Independent reassessments

6 SUMMARY AND CONCLUSIONS

The final reporting of the EXAM-HRA project provides an overview of the assessments done by developing a “Guidance on methods” document. This document is presented in the form of a Practical Guide to HRA.

The human failure events (HFE) presented in the survey report and application framework has been used to develop a “Guidance on scope” document presented in the Application guide [6].

The recommendations presented in this report are based on the experience gained from the case studies and the findings regarding plant features as well as features of the HRA and PSA applications. The recommendations made for the HRA process are supported by specific observations from the case studies.

The recommendation presented is structured according to a set of HRA "key words" that represents important steps in the HRA process. The key words have been chosen by the EXAM-HRA project team of HRA/PSA practitioners/experts and are supported by our outlook on available methods and a summary of international guidance related to HRA. Practical guidance and recommendations are provided for all areas in the ASME PRA standard.

The project format provides great opportunities to learn about important aspects influencing the HRA applications, such as:

- Actual plant differences
- HRA aspects
- PSA aspects

The work has included involvement of plant staff in the EXAM-HRA working group itself as well as plant staff during plant visits when developing the case studies and the guidance. A lot of experience has been gathered on ”how to do” and ”what to do”.

Open issues discussed in working group that may call on further developments are:

- Conflict interest: In several of the case studies it has been noted that operator actions may have conflict of interest (COI) as an element that need to be assessed in the HRA. If the COI element is not taken into account the quantified HEP value may be optimistic.
- The balance between diagnosis/decision/implementation modelling in terms of level of detail and resources.
- Error of commission: Errors of commission (EOC) means the potential to make a situation more serious. EOC are strongly influenced by the way the alarm patterns and instruments of different scenarios may be nearly similar. The control room team will then diagnose the wrong initiating event, and decide for the wrong actions.
- The Nordic industry should benefit from a better documentation of the Enhanced Bayesian THERP methodology.

If the practical guide will fulfil its purpose is dependent on its use and application. The main future benefits are expected to:

- strengthen the HRA process in the development or updating of the plant specific PSAs;
- support the HRA practitioners in their dialog and interaction with PSA experts and human factor specialists;
- support the assessment of available applications when used as a ”sanity check” of the results derived.

The aim is to improve consistency in in-depth HRA and human error probability (HEP) assessment by providing a common basis for methods and guidance for HRA application and assessment.

This overview and the practical recommendations on good practice shall support the assessment of plant specific aspects in HRA and ultimately improve the plant safety.

7 REFERENCES

[1] PSAM9 paper No. 0260, *Quantifying the Unimaginable – the Case for Human Performance Limiting Values*, Barry Kirwan, Ian Umbers, Jim Edmunds, and Huw Gibson

[2] IAEA Specific Safety Guide No. SSG-3, *Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants*

[3] Davoudian, K., J.S. Wu, and G. Apostolakis, *Incorporating Organizational Factors into Risk Assessment through the Analysis of Work Processes*, Reliability Engineering and System Safety, 45: 85–105, 1994 (http://pbadupws.nrc.gov/docs/ML0906/ML090650533.pdf).

[4] B Kirwan and L. K. Ainsworth, *A Guide To Task Analysis: The Task Analysis Working Group*, (1992)

[5] B Kirwan, *A Guide To Practical Human Reliability Assessment*, (1994)

[6] NPSAG Report 11-004-03 EXAM HRA Application guide. (ES konsult report 2012020-013) 2014-12-16

[7] EXAM HRA project report: Survey and process for selection of scenarios to be included in HRA assessment, 2010006-013, 2013-10-13

[8] ASME PRA standard: ASME/ANS RA-Sa-2009 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications. American Society of Mechanical Engineers 2009.

[9] Swain, A. D., & Guttmann, H.E. (1983) Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications. NUREG/CR-1278, Rev. 1. Sandia National Laboratories.

[10] Rasmussen, J. Skills, rules, knowledge: Signals, signs and symbols and other distinctions on human performance models, IEEE Trans. Syst., Man, Cybern. 13 3, 1983.

[11] Wakefield, D.J., et al., SHARP1—A Revised Systematic Human Action Reliability Procedure, Interim Report, Electric Power Research Institute (EPRI), NP-7183-SL,December 1990.

[12] NPSAG Report 11-004-01, Exam HRA Final Summary Report, March 2015

[13] Porthin, M., State-of-the-Art of Human Reliability Analysis for Nuclear Power Plants, Research Report VTT-R-05497-14, VTT Technical Research Centre of Finland, 2014.

APPENDIX A – OVERVIEW OF HRA METHODS AND REFERENCE DOCUMENTS

In this appendix, an overview is given on relevant guidelines and standards concerning the PSA and HRA process for NPPs in general as well as on evaluations of HRA methods [13]. The main documents on the HRA process, as well as their main content, are listed in Table 5 below.

Specific HRA methods have been evaluated by several organizations and projects. The most relevant ones include:

- NUREG-1842, Evaluation of Human Reliability Analysis Methods Against Good Practices, United States Nuclear Regulatory Commission (NRC), 2006
    - Particular focus on the extent to which the HRA methods provide guidance to satisfy the good practices reported in NUREG-1792.
    - The HRA methods are also evaluated against the Probabilistic Risk Assessment (PRA) Standard (RA-S-2002) promulgated by the American Society of Mechanical Engineers (ASME).
    - Includes observations regarding the respective strengths and limitations of the HRA methods, as well as summaries of the scope, underlying knowledge
- HSE RR679, Review of human reliability assessment methods, HSE (Health and Safety Executive), 2009
    - Focuses on the capability, strengths and weaknesses of the HRA methods.
- The international HRA empirical study (2007-2013)
    - A three-phase multinational, multi-team effort supported by the Organization for Economic Cooperation and Development (OECD) Halden Reactor Project, the Swiss Federal Nuclear Safety Inspectorate, the U.S. Electric Power Research Institute, and the U.S. Nuclear Regulatory Commission (NRC).
    - The objective is to develop an empirically based understanding of the performance, strengths, and weaknesses of different HRA methods.
    - A follow-up project exists, named The US HRA Empirical Study.
- OECD CSNI WGRISK / WGHOF task on Establishing Desirable Attributes of HRA Methods for Nuclear Risk Assessment
    - The objectives of the activity are to:
        - Derive a set of attributes against which HRA methods can be evaluated

    - Conduct an evaluation of HRA methods used in OECD member countries for nuclear risk assessment
    - Provide a basis from which HRA users can select appropriate HRA methods for different HRA applications
  - Final report of the task group to appear during 2014.

Table 6 below gives an overview on which HRA methods have been accounted for in the evaluations listed above.

Table 5 Appendix A – Reference documents on HRA methodology.

No.	Organization	Document Number	Year of issue	Document name	Key points / Main content
{1}	International Atomic Energy Agency (IAEA)	Safety Series No. 50-P-10	1995	Human Reliability Analysis in Probabilistic Safety Assessment for Nuclear Power Plants: A Safety Practice	Practical guide describing the steps needed for incorporating HRA into PSA and the documentation that should be provided. The publication is officially no longer valid. The content is however still relevant.
{2}	International Atomic Energy Agency (IAEA)	IAEA-TECDOC-1511	2006	Determining the quality of probabilistic safety assessment (PSA) for application in nuclear power plants	Provides information regarding the features, written in the form of attributes of the major PSA elements (including HRA), which are appropriate for carrying out various PSA applications.
{3}	United States Nuclear Regulatory Commission (NRC)	NUREG-1792	2005	Good Practices for Implementing Human Reliability Analysis (HRA)	Good practices for performing HRAs and reviewing HRAs to assess their quality. The good practices are of a generic nature and are not tied to any specific HRA methods or tools. They support the implementation of Regulatory Guide RG 1.200 for Level 1 and limited Level 2 internal event PRAs with the reactor at full power. The report is not a standard and does not provide de facto requirements; rather, is intended for use as a reference guide.
{4}	The Institute of Electrical and Electronics Engineers (IEEE)	IEEE Std 1082-1997(R2010)	1997, reaffirmed 2010	IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations	A structured framework for the incorporation of human/system interactions into probabilistic risk assessments for nuclear power plants.
{5}	Paul Scherrer Institute (PSI)	HSK-AN-3584	2000	Guidelines for the Regulatory Review of Human Reliability Analysis in PSA	HRA quality is addressed in the guidelines in terms of 97 indicators.
{6}	Swiss Federal Nuclear Safety Inspectorate (ENSI)	ENSI-A05/e	2009	Probabilistic Safety Analysis (PSA): Quality and Scope	Defines the quality and scope requirements regarding PSA Level 1 and 2 for internal and external events including requirements on HRA.
{7}	European Utility Requirement for LWR Nuclear Power Plants (EUR)	EUR Volume 2, Chapter 17 – PSA Methodology	2012	EUR Volume 2, Chapter 17 – PSA Methodology	The main objective of the EUR organisation is to produce a common set of Utility requirements, endorsed by the major European electricity producers for the next generation of LWR nuclear power plants.

Table 6 Appendix A – Overview on HRA methods considered in HRA reference documents and studies

Acronym	Full name	NUREG-1842	HSE RR679	Int. HRA empirical study	OECD CSNI WG Risk / WGHOF
ASEP	Accident Sequence Evaluation Programme	X	X	X	X
APJ	Absolute Probability Judgement		X		
ATHEANA	A Technique for Human Error Analysis	X	X	X	X
CAHR	Connectionism Assessment of Human Reliability		X		
CBDT	EPRI Caused Based Decision Tree	X		X	X
CESA	Commission Errors Search and Assessment		X		
CESA-Q	Commission Errors Search and Assessment – Quantification			X	
CODA	Conclusions from occurrences by descriptions of actions		X		
CREAM	Cognitive Reliability and Error Analysis Method		X	X	X
DT	Decision Trees			X	
Enhanced Bayesian THERP	Enhanced Bayesian Technique for Human Error Rate Prediction			X	X
EPRI	Electric Power Research Institute HRA Calculator®	X			
FLIM	Failure Likelihood Index Methodology	X			X
HCR/ORE	Human Cognitive Reliability / Operator Reliability Experiments	X			X
HEART	Human Error Assessment and Reduction Technique		X	X	
HRMS	Human Reliability Management System		X		
HURECA	Human Reliability Evaluator for Control Room Actions				X
INTENT	Not an acronym		X		
JHEDI	Justified Human Error Data Information		X		
K-HRA	Korean Human Reliability Analysis			X	
MERMOS	Method d'Evaluation de la Realisation des Missions Operateur pour la Surete (Assessment method for the performance of safety operation.)		X	X	X

Acronym	Full name	NUREG-1842	HSE RR679	Int. HRA empirical study	OECD CSNI WG Risk / WGHOF
NARA	Nuclear Action Reliability Assessment		X		X
PC	Paired comparisons		X		
SHARP1	A Revised Systematic Human Action Reliability Procedure	X			
SLIM-MAUD	Success likelihood index methodology, Multi-Attribute Utility Decomposition	X	X		
SPAR-H	Standardized Plant Analysis Risk Human Reliability Assessment	X	X	X	X
THERP	Technique for Human Error Rate Prediction	X	X	X	X

APPENDIX B – OUTLOOK ON GUIDANCE

B.1 HFE DEFINITION – INTRODUCTION

The definition of HFE means to describe how to model the impact of the failure in the PSA model so that the HFEs are consistent with the structure and level of detail in the accident sequence models.

The definition of each HFE is also important as preparation for estimation of its probability, and the definition is completed by specifying the scenario specific factors. For Category C actions such scenario specific factors can include the following:

- availability of cues and/or other indications for alerting the operators to the need for action;
- the scenario specific procedural guidance;
- time available for successful completion of response;
- timing of cues relative to accident progression;
- availability of systems, or components identified in the procedures;
- the tasks comprising the required response.

Other aspects related to HFE definitions are related to **selection** of the operator actions that are included in the PSA, what kind of **data collection** that is needed in order to perform the HRA and the **qualitative analysis** that describes the tasks that need to be performed as well as the performance shaping factors used. These additional aspects are described separately in sections below.

B.1.1 HFE DEFINITION / SELECTION – IDENTIFICATION

It is important that the process for identification of human failures events that could lead to either Category A, B or C is systematic and transparent.

- Category A actions represent alignment/configuration errors following testing or maintenance, and miscalibration are of particular significance.
- Category B actions represent human errors that may lead to an initiating event that shall be taken into account when initiating event frequencies are determined.
- Category C actions represent those human actions that shall be taken into account in the context of accident sequence analysis.

Even though it can be noted that more guidance is given in the literature about identification of Category A and C actions compared to Category B it can be concluded that identification of Category B actions should be performed in a similar systematic process.

It shall also be noted that during the identification process, operator actions that will have a negative impact on the accident sequence (Errors of

Commission - EOCs) should also be identified or it shall at least be stated whether such actions have been identified or not.

In the identification process measures to restore a system (recovery) should also be identified. It is however noted in the ENSI PSA Guide (No. {6} in Table 6 that such measures should only be taken into account in the case of independent component failures, i.e. not in the case of component CCF.

The identification process is for instance described in the following way in IAEA-TECDOC-1511 (No. {2} in Table 6).

Table 7 Appendix B – Identification process of Category A and C events.

Category A: The task includes a thorough identification of specific routine activities, which, if not performed correctly, impact the availability of equipment necessary to perform the system functions modelled in the PSA.	
Through a review of procedures and operational practices, those test and maintenance activities that require realignment of equipment from its normal operational or standby status are identified for those systems and components required to perform the functions required to respond to the initiating events modelled.	Particular attention should be paid to activities that can disable multiple trains of a system simultaneously (e.g. the automatic initiation of the standby liquid control system in a BWR is typically disabled for test purposes).
Through a review of procedures and practices, those calibration activities are identified that, if performed incorrectly, have the capability of defeating the automatic initiation of standby safety equipment or of rendering required functions of systems or components unavailable.	In particular, those activities that have the potential to affect equipment in multiple trains of a redundant system, or in diverse systems, e.g. as a result of using inappropriate calibration procedures or faulty or improperly calibrated calibration equipment, are identified. Examples: Incorrect calibration of steam generator level sensors; incorrect setting of torque switches.
The procedures which allow detecting the faulty alignment or calibration are also reviewed.	
Category C: Identification of the set of operator responses following the initiating event required for each of the accident sequences modelled is performed in a systematic way using appropriate information sources.	
The set of operator responses required to control and safely shutdown the plant following an initiating event is generated by reviewing all relevant operating procedures (e.g. emergency operating procedures, abnormal operating procedures, and annunciator response procedures) to determine what actions are required as a function of the plant status represented in the development of the accident sequences.	The following operator responses are identified: • Actions required to initiate, control, isolate, or terminate systems as required to prevent or mitigate core damage. • Actions required to change the status of components in order to fulfil a function required to prevent or mitigate core damage.
This task is an integral part of the development of the accident sequence model.	

B.1.2 HFE DEFINITION / SELECTION – SCREENING

During the early stages of the PSA/HRA process it is quite common to use screening criteria in order to determine the importance of the equipment or operator action in question. The importance measure (e.g. CDF contribution) is then used to determine whether the equipment or operator action can be:

- screened out from the PSA, i.e. not included,
- analysed using simplified but conservative models, or
- needs to be analysed more in detail.

The international guidance provides the analysts both with qualitative and quantitative criteria that need to be taken into account during the HRA process. The general guidance is of course that any screening process applied should be well documented and applied in a systematic and transparent manner and that screening should only be made when it can be argued that possible contribution would be small compared to other modes of unavailability for the equipment in question.

In the table below some general rules that need to be considered during screening of Category A actions are given.

Table 8 Appendix B – Rules for screening of Category A actions

<table>
<tr><th colspan="2">General rules for screening of Category A actions that need to be considered.</th></tr>
<tr><td colspan="2">For unique, one-of-a-kind activities, screening should only be made when it can be demonstrated that defences in place against the latent equipment failure are sufficient to reduce the Category A failure probability below that of other modes of unavailability of the equipment.</td></tr>
<tr><td colspan="2">It shall be clear that dependencies among multiple HFEs appearing in an accident sequence are conservatively accounted for.</td></tr>
<tr><td colspan="2">Activities that would result in multiple trains of a system being unavailable should be analysed in more detail since it is comparable with CCF probabilities.</td></tr>
<tr><th colspan="2">Example of defences against latent equipment errors that can be used as qualitative screening criteria for Category A actions</th></tr>
<tr><td>ENSI PSA Guide (No. {6} in Table 6):
• Automatic actuation on demand
• Functional tests are conducted that will reveal any error.
• Status of equipment is displayed in control room and this is periodically controlled and modifiable from the control room, or
• there is a requirement to check status at least once per shift.</td><td>IAEA-TECDOC-1511 (No. {2} in Table 6):
• Equipment is automatically re-aligned on system demand.
• Full functional test is performed on completion of maintenance.
• Equipment status is indicated in the control room and can be effected from there.
• Equipment status is required to be frequently checked (e.g. once per shift), and indications of misalignment are clear.</td></tr>
</table>

For Category A actions the "Good Practice" document (No. {3} in Table 6) gives recommendations on screening values to be applied as follows:

- Individual screening values should not be less than 0.01 and
- The joint failure probability of multiple HEPs in a sequence should not be lower than 0.005.

Guidance related to screening of Category B and C actions are more limited compared to Category A actions. But given the amount of Category A actions to be analysed in a normal PSA the need for more specific guidance may be higher for Category A compared to B and C.

In a similar way as for Category A the "Good Practice" document provides recommendations on screening criteria for Category C actions as follows:

- The use of conservative HEP estimates to screen out unimportant HFEs is acceptable provided:
  - It is clear that the individual values used are overestimations of the probabilities if detailed assessments were to be performed and
  - Dependencies among multiple HFEs appearing in an accident sequence are conservatively accounted for.
- Individual screening values should never be less than 0.1 and the joint probability of multiple HEPs in a sequence should not be lower than 0.005.

Since screening values by definition are conservative estimations it is important to recognize the potential danger of keeping the screening values as the final HEP assessment in the PSA since this may obscure findings about plant susceptibilities that have been modelled in a more realistic manner.

B.1.3 HFE DEFINITION / SELECTION – ERRORS OF COMMISSION

As described in section B.1.1, operator actions that will have a negative impact on the accident sequence (errors of commission, EOCs) should be identified or it shall at least be stated whether such actions have been identified or not.

One guidance document that provides some more detail about this is the "Good Practice" document (No. {3} in Table 6) where the statements can be summarized as described below.

Table 9 Appendix B – Guidance on error of commission

It is recommended that future HRA/PRAs identify and model, to the extent necessary, potentially important EOCs. For any EOCs modelled, the guidance given in this report for either pre-initiators or post-initiators are applicable for identifying, modelling, and quantifying EOCs. That is, the **same good practices apply whether the error is one of omission or commission**.
As a Minimum, **search for conditions that may make EOCs more likely**. The use of risk in any issue assessment should at least ensure that conditions that promote likely EOCs do not exist. For example, it should be ensured that such conditions have not been introduced by a plant change or modification, or that the plant is not more susceptible to EOCs under the unique set of conditions being examined.

When considering the potential for situations that may make EOCs somewhat likely, the premise of any evaluation should be as follows: • Operators are performing in a rationale manner (e.g., no sabotage), and • Procedural and training guidance is being used by the crew based on the plant status inputs they are receiving. Using this premise, EOCs are considered to be largely the result of problems in the **plant information/operating crew interface** such as: • wrong or inadequate information is presented, or • the information can be easily misinterpreted. or in the procedure-training/operating crew interface where **procedures/training do not cover the actual plant situation** very well because they provide: • ambiguous guidance, • no guidance, • or even unsafe guidance • for the actual situation that may have evolved in a somewhat unexpected way. In either case, significant mismatches can occur between the scenario conditions and the crew's understanding of those conditions. Such mismatches should be searched for and their potential for leading to EOCs should be examined.

In addition to the above guidance the "Good Practice" document also provides guidance on how to ensure that EOC-prone conditions do not exist or have not been introduced as part of a plant change. Hence, during the HRA process one should look for situations where one or more of the characteristics described below exist or are introduced as a consequence of a plant change.

Table 10 Appendix B – How to ensure that EOC prone conditions do not exist

Potential impact due to mismatches between scenario context and plant information/interface
Potential impacts of mismatches between scenario context and plant information/interface can be identified by looking for actions that operators may take that: • would fail or otherwise make unavailable a PSA function or system, or • would reduce the accident mitigating redundancy available, or • would aggravate the accident sequence since the action to be performed is based on only one primary input/indication for which there is no redundant means to verify the true plant status.
During identifying of EOC-prone conditions, one should keep in mind that multiple indications may use the same faulty input and therefore a single fault may actually affect multiple inputs observable to the operator.
Potential impacts due to problems with procedure-training interface

Potential problems with procedure-training interface can be identified by looking for actions that operators may take that:

- would fail or otherwise make unavailable a PSA function or system, or
- would reduce the accident mitigating redundancy available, or
- would aggravate the accident sequence the action to be performed because the procedures (including entry conditions) and/or training guidance:
  - to become ambiguous/unclear (e.g., vague criteria as to when to abandon the main control room)
  - introduce a repetitive situation in the response steps where a way to proceed out of the procedure and/or the specific repetitive steps is not evident (e.g., at the end of a series of steps, the procedure calls for a return to a previous step with no clear indication as to how the operators ultimately get out of the repetitive loop of steps)
  - place the operators in dilemma conditions without some guidance/criteria as to how to “solve” the dilemma (e.g., being vague as to whether or not to shut down a diesel with a cooling malfunction when all other ac power is unavailable)
  - require the operators to rely on memory, especially for complex or multi-step tasks
  - require the operators to perform calculations or make other manual adjustments, especially in time-sensitive situations

B.2 HFE DEFINITION / DATA COLLECTION – INTRODUCTION

In order to perform an HRA that is plant-specific and takes into account possible dependencies and uncertainties it is important to get a good understanding of as many factors/aspects as possible of the actions to be analysed. This can be exemplified with the following statements taken from the "Good Practise" document (No. {3} in Table 6) and in IAEA SSG-3 [2].

IAEA SSG-3: The human reliability analysis should be carried out in close cooperation with the plant operating and maintenance staff to ensure that the analysis reflects the design features of the plant and its operation under normal and accident conditions.

"Good Practise": If the PSA is to realistically include human actions, the modelling of human interactions must consider each action evaluated in the context of a complete accident scenario or sequence of events. Understanding an accident sequence context is a complex, multifaceted process. The interaction of plant hardware response and the response of plant operators must be investigated and modelled accordingly.

One of the first steps in the HRA process is to collect necessary information/data. The kind of data that is covered in here is divided into the following three headings:

- Plant organization & Management
- Task specific information
- Task context

These headings, or attributes related to data collection, are very general in their nature but try to cover different aspects that is of importance when performing an HRA. Of course, the data collected during the HRA should also cover the needs of selected Performance Shaping Factors that is taken into account in the analysis.

The data collection in this aspect is as important for the performance as the plant familiarization for the performance of the PSA as a whole. The data collection can therefore be seen as a part of the plant familiarization, see for instance Chapter 4 in IAEA SSG-3 [2].

B.2.1 HFE DEFINITION / DATA COLLECTION – PLANT ORGANIZATION & MANAGEMENT

Specific guidance on how to incorporate organizational and management issues into the HRA is generally not given in the documents that have been included in the survey.

As an example it can be mentioned that much of the guidance given in the "Good Practise" document (No. {3} in Table 6) is aimed at understanding the context associated with each modelled human action, and how that context affects both the definition of HFEs and an assessment of their probabilities. It should however be noted that even though organizational influences are part of understanding the full context associated with human performance and the document addresses some related contextual factors (such as staffing resources and administrative controls and biases), it does not specifically address organizational influences as part of the context of human performance. Although work has been done in this area, see for instance [3], the treatment of these influences - and particularly how they are accounted for in estimating human error probability - are still subject to research.

Even though current HRA methodologies may need to be further developed in order to quantitatively address aspects of organizational nature it is nevertheless important for an HRA analyst to understand possible influence that the organization as a whole can have on the specific operator action that is being analysed. This is especially important when it comes to aspects related to decision making, i.e. how and by whom a certain decision made about start or stop a certain function in a given scenario.

As stated in the "Good Practice" document section 3.1.3.2 this can be done by performing Field Observations and Discussions. In addition to the review of plant documents, the HRA should include walk downs of relevant actions (particularly local actions), observations of simulator exercises, talk-throughs of accident scenarios and related actions with plant operators and trainers, and other field observations and discussions, as needed.

B.2.2 HFE DEFINITION / DATA COLLECTION – TASK SPECIFIC INFORMATION

During the HRA process it is important to collect information about the specific task that is to be performed and to find out how the work is distributed within the control room team or the shift during accident conditions. In relation to the latter aspect it is important to understand what parallel duties exist for the shift leader and the deputy shift leader; to what extent they are available for either work in parallel to mitigate the accident, or as personnel redundancy for the operators. It is also important to understand when additional resources will become available (especially during long term scenarios), like shift technical advisor, crisis management staff, picket engineer[9], etc. The bullet list below has been put together from the "Good Practise" document (No. {3} in Table 6). For each bullet a reference is made to the related section in the "Good Practise" document. The results of these activities may add to the list of actions and/or help interpret how procedural actions should be defined based on how they are actually carried out.

- Review Pre-Initiator Procedures, Actions, and Equipment (4.1.3.1):
  - All routine (scheduled) testing and maintenance, as well as calibration procedures that affect equipment to be credited in the PRA, should be identified and reviewed.
  - Actions and equipment specified in the procedures should be examined to determine whether misalignment or miscalibration could occur and render the equipment unavailable or faulty.
- Review Post-Initiator Related Procedures and Training Materials (5.1.3.1):
  - Plant-specific emergency operating procedures (EOPs), abnormal operating procedures (AOPs), annunciator procedures, system operating procedures, and severe accident management guidelines (SAMGs) should be reviewed.
  - Other relevant special procedures (e.g., fire emergency procedures) should also be reviewed as appropriate.
  - Observations of simulator exercises and talk-throughs of accident scenarios and related actions with plant operators and trainers can support the identification of post-initiator human actions at this stage.
- Perform Talk-Throughs, Walk downs, Field Observations, and Simulator Exercises (as necessary) to Support the Modelling of Specific HFEs (5.2.3.3):
  - To fully understand the nature of the act(s) and help define the HFEs and their context, additional reviews, talk-throughs, walk downs, field observations, and simulator exercises are performed. These can look into aspects such as:
    - who performs it,
    - what is done,
    - how long does it take,
    - whether there are special tools needed,
    - whether there are environmental issues or special physical needs,

[9] Picket engineer is a specialist engineer who is already responsible for tasks within a technical or operational Division during his normal working days, and whose aim, during his picket engineer assignment, is to maintain the safety and availability of the plant during normal operation as well as during emergencies. (https://inis.iaea.org/search/search.aspx?orig_q=RN:41109576)

    - whether there is a preferred order of use of systems to perform a specific function,
    - etc.
- Account for Plant- and Activity-Specific PSFs in the Detailed Assessments of Post-Initiator HEPs (5.3.3.5).

B.2.3 HFE DEFINITION / DATA COLLECTION – TASK CONTEXT

Section 3 in the "Good Practice" document (No. {3} in Table 6) concludes that if the PSA is to realistically include human actions, the modelling of human interactions must consider each action evaluated in the context of a complete accident scenario or sequence of events. Understanding an accident sequence context is a complex, multifaceted process. The interaction of plant hardware response and the response of plant operators must be investigated and modelled accordingly. The following characteristics (among others) need to be understood and reflected upon, as necessary, in the model of a specific human action or group of actions:

- plant behaviour and conditions,
- timing of events and the occurrence of human action cues,
- parameter indications used by the operators and changes in those parameters as the scenario proceeds,
- time available and locations necessary to implement the human actions,
- equipment available for use by the operators based on the sequence,
- environmental conditions under which the decision to act must be made and the actual response must be performed,
- degree of training, guidance, and procedure applicability,
- additional tasks of the control room team, which are not directly related to the task concerned (either external communication or additional tasks due to accident sequence).

Section 5.1.3.2 in the "Good Practise" document addresses the topic of "Review Functions and Associated Systems and Equipment to be modelled in the PSA". The PSA team’s plant and system knowledge should be used to identify critical functions and equipment needed and not needed for the given accident scenario. In addition, ways the equipment can functionally succeed and fail should be determined, along with (1) ways the operators are intended/required to interact with the equipment, and (2) how they are to respond to equipment failure modes that can cause undesired conditions for the mitigation. During the identification process, it is helpful to use action words such as actuate, initiate, isolate, terminate, control, change, etc. so that the desired actions are clear.

B.3 HFE DEFINITION / QUALITATIVE ANALYSIS – INTRODUCTION

The qualitative part of the HRA process is as important as the quantitative part, if not even more important. From the quantitative part only, it is very hard to understand how the analysts have come to the specific HEP in question and why (besides just doing the math). From the qualitative part it can however be possible for someone familiar with the plant, but not very well familiar with HRA techniques to judge whether the view of the analyst concerning the conditions of work is realistic or not realistic for a specific action.

The qualitative analysis should therefore be an important part of the HRA documentation which should include aspects such as (see section 7 in "Good Practise" document (No. {3} in Table 6) the following, but only to the extent applicable for the application:

- the overall approach and disciplines involved in performing the HRA including to what extent talk-throughs, walk downs, field observations, and simulations were used,
- summary descriptions of the HRA methodologies, processes, and tools used to achieve the following purposes:
  - identify the pre- and post-initiator human actions,
  - screen pre-initiators from modelling,
  - model the specific HFEs, including decisions about level of detail and the grouping of individual failures into higher order HFEs, and
  - quantify the HEPs with particular attention to the extent to which plant and accident sequence-specific information was used, as well as how dependencies were identified and treated.
- assumptions and judgments made in the HRA, their bases, and their impact on the results and conclusions (generic or on a HFE-specific basis, as appropriate),
- for at least each of the HFEs important to the risk decision to be made, the PSFs considered, the bases for their inclusion, and how they were used to quantify the HEPs, along with how dependencies among the HFEs and joint probabilities were quantified,
- sources of data and related bases or justifications for the following:
  - screening and conservative values,
  - best estimate values and their uncertainties with related bases.
- results of the HRA including a list of the important HFEs and their HEPs, and,
- conclusions of the HRA.

An important purpose for the qualitative analysis and how it is documented is to ensure traceability and defensibility of the HRA.

B.3.1 HFE DEFINITION / QUALITATIVE ANALYSIS – TASK ANALYSIS

A general definition of the term "task analysis" can be to "analyse the task in question in sufficient level of detail for the quantitative assessment that is to be made". Task analysis is also often mentioned as a specific technique to breakdown a complex task into manageable subtasks that can be analysed with the HRA methodology that is being used. No formal requirements have been identified regarding how such a task analysis should be performed and on what level of detail that is needed.

Below is a brief overview given of what a task analysis is and how it can be performed. The basis for the overview is taken from references [4] and [5].

Task analysis is the process of critically examining task factors – the operator’s resources, constraints and preferences – in order to establish how these influence human operations in the attainment of system goals.

The application of task analysis methods provides the user with a “blueprint” of human involvements in a system, building a detailed picture of that system from the human perspective. Such structured information can then be used to ensure that there is compatibility between system goals and human capabilities and organizations, so that the system goals will be achieved.

One of the most popular and most important techniques for performing a task analysis is the HTA – Hierarchical Task Analysis – which describes the task from its top-level goals down to the level of individual operations, an example is given in the figure below.

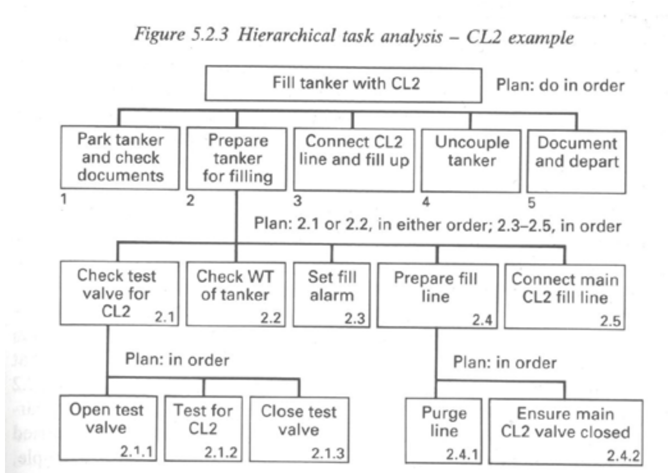

Figure 3 Appendix B – Example of hierarchical task analysis

The analyst begins by stating a goal that a person/system has to achieve. This is then re-described into a set of sub-operations and a plan (or plans) governing when they are carried out. To perform a HTA you use the concepts *Goal, Tasks, and operations*:

- *Goal* - are desired states of the system, the system objective that can be achieved by a varying range of tasks

- *Tasks* - is composed of a set of operations. All described tasks should together completely define how to achieve the top goal, i.e. there must not be an additional necessary task missing nor any superfluous tasks.
- *Operations* - an operation is what is actually done in a situation, usually a description of a behaviour or cognitive activity that is carried out to achieve the task's objective.

Another common technique is referred to as the Tabular Task Analysis, TTA. The TTA takes each particular task-step or operation and considers specific aspects, such as: Who is doing the operation? What displays are being used? What feedback is given? What errors could occur? The column titles will vary depending on the purpose of the task analysis, an example is given below.

Table 11 Appendix B – Example of tabular task analysis structure

Task step no.	Task Goal	Information available to the operator	Required action	Feedback	Communications	Possible errors, distractions, time available, skills/knowledge required
#	xxx	xxx	xxx	xxx	xxx	xxx

TTA approaches enable the highly detailed observation of what is guiding the operator through a series of predefined events, or a series of PSA-defined events and failures. They offer both a sound task-analysis basis for further consideration of performances and errors, and beneficial medium for the discussion of human-error problems with other parties – whether PSA assessors, operators or designers.

The combination of using a HTA and TTA is a very powerful tool for detailed evaluation of interfaces, since HTA gives the analyst a firm basis for understanding the system, while the TTA, on the other hand, can be used first systematically to investigate the ergonomics aspects of the system and then to justify problems identified on the grounds of likely consequences or errors.

B.3.2 HFE DEFINITION / QUALITATIVE ANALYSIS – PSF ASSESSMENT

What performance shaping factors (PSFs) are taken into account is often given by the HRA method used. Of importance is to account for plant- and activity-specific PSFs during the assessment of all categories of operator actions (Category A, B and C). During the HRA assessment it should be determined whether a PSF is a weak/strong positive, neutral (or not applicable), or negative influence, regardless of the method/tool. The method/tool being used should provide definitions and guidance for assessing PSFs qualitatively (e.g., terms like "good," "adequate," "poor" have to be defined as precisely as possible to avoid ambiguities among the analysts), along with a way to interpret the results into a quantified HEP, that can be used in conjunction with this information.

Examples of performance shaping factors for pre- and post-initiators are given below.

Table 12 Appendix B – Example of PSFs for pre- and post-initiators

<table>
<tr><td colspan="2">Examples of potentially important PSFs according to "Good Practice" document (No. {3} in Table 6)</td></tr>
<tr><td>Pre-initiators (Cat. A)</td><td>Post-initiators (Cat. C)</td></tr>
<tr><td>• written work plans,
• procedures,
• training,
• complexity and number of steps,
• reliance on memory,
• ergonomics, and
• the task environment</td><td>Main control room:
• procedures (and how the procedures are implemented),
• training,
• task complexity,
• workload,
• team dynamics, and
• scenario timing
Additional PSFs for local actions:
• workload (staff available for the action),
• communication requirements,
• number of steps,
• reliance on memory,
• ergonomics,
• task environment,
• accessibility,
• special fitness needs, and
• the need and location of special tools.</td></tr>
<tr><td colspan="2">PSFs that shall be taken into account according to ENSI PSA Guide (No. {6} in Table 6) for Post-initiators (Cat. C).</td></tr>
<tr><td colspan="2">• Characteristics and frequency of training and experience.
• Quality of written procedures.
• Availability of instrumentation and quality of the HMI.
• Clarity/unambiguousness of cues and indications.
• Time available and time required to complete the task.
• Complexity of the response (e.g. coordination and communication requirements).
• Environmental aspects.
• Accessibility, availability, and adequacy of required tools and equipment.</td></tr>
</table>

When performing HRA for hazards the hazard specific conditions shall be considered which might impact the PSFs chosen. Below, some examples of hazard specific conditions related to PSFs are given.

Table 13 Appendix B – PSFs to take into consideration for hazard conditions

Specific conditions that shall be taken into account when performing HRA for hazards according to ENSI PSA Guide (No. {6} in Table 6).
General conditions for internal and external hazards: • Increased stress and confusion. • Reduced availability of personnel. • Limited accessibility and habitability of relevant areas (e.g. rooms). • Failed or erroneous instrument indications. • Additional workload on personnel. • Additional difficulties in the detection/diagnosis of certain hazards. • Limited accessibility to areas of the plant. • Adverse environmental aspects caused by fire/flooding
Specific aspects that need to be considered for earthquakes • Choice of parameters that characterize an earthquake and their assumed effect on the error probabilities shall be defined and justified. • The approach applied and the numerical values (such as increase factors) shall be defined and justified. • The psychological and possibly physical effects of the earthquake shall be taken into account during HEP assessment.

B.4 QUANTIFICATION – INTRODUCTION

Quantification is just one of the tasks that need to be performed during a HRA. Most HRA methods are primarily quantification tools and, therefore, do not address (or only partially address) many other steps of the HRA process (e.g., identifying human failure events to be modelled). This can be seen as a limitation of those methods but it may not be a drawback therefore and no fault should be insinuated where the method was not intended to cover these other aspects of the HRA process.

B.4.1 QUANTIFICATION – METHODOLOGY

Even though some specific regulatory guides may state which HRA methodologies have been accepted by the regulator in question, there is not much guidance given regarding what specific method(s) to be used for different purposes. It is only requested that the methodology used should be well documented and able to assess the plant/task specific inputs and scenarios explicitly.

Important aspects of the quantification process are given in section 0, i.e. that the methodology, how it has been applied and the results it provides should be transparent, reproducible, reasonable, and adequate, i.e. support the PSA with plant-specific HEPs.

B.4.2 QUANTIFICATION – PSF CALCULATION

As section B.3.2 deals with requirements and guidance relating to PSF assessment, i.e. selection of PFSs, this section deals with requirements and guidance related to how to take PSFs into account during the quantification process.

Guidance on how to take chosen PSFs into account during the HEP quantification is however rather limited since this is something that usually is more or less dictated by the chosen HRA method. The type of guidance given is more related to making sure the appropriate PSFs have been included, the resulting HEP is reasonable with respect to the PSFs, and that dependencies have been taking into account.

Table 14 Appendix B – Guidance on PSF quantification

<table>
<tr><th colspan="2">Summary from sections dealing with quantification in the "Good Practise" document (No. {3}in Table 6) is given here with references to the different sections.</th></tr>
<tr><td>Pre-Initiator Quantification:
Pre-initiator HEP assessments should account for the most relevant plant- and activity-specific PSFs in the analysis. Potentially important PSFs include written work plans, procedures, training, complexity and number of steps, reliance on memory, ergonomics, and the task environment (4.4.3.4).
The pre-initiator HEPs (excluding the screening HEPs) should be reasonable from two standpoints: (1) first and foremost, relative to each other (i.e., the probabilistic ranking of the failures when compared one to another), and (2) in absolute terms (i.e., each HEP value), given the relative strengths of the positive and negative PSFs identified as being important and the presence or absence of recovery factors. Example evaluation techniques include consideration of actual plant history, comparisons with results of other analyses, and qualitative understanding of the actions and their contexts by experts (4.4.3.8).</td>
<td>Post-Initiator Quantification:
Post-initiator HEP assessments should account for the most relevant plant and activity-specific PSFs. Potentially important main control room PSFs include (but are not limited to) procedures (and how the procedures are implemented), training, task complexity, workload, team dynamics, and scenario timing. Potentially important PSFs for local actions include (but are not limited to) procedures (and how they are implemented), training, task complexity, workload (staff available for the action), team dynamics, scenario timing, communication requirements, number of steps, reliance on memory, ergonomics, task environment, accessibility, special fitness needs, and the need and location of special tools (5.3.3.5).
Dependencies among the post-initiator HEPs in an accident sequence should be quantitatively accounted for in the PRA model by virtue of the joint probability used for the HEPs. Once all the relationships are considered and the dependencies are included in the HEP values, the total combined probability of all the HFEs in the same accident sequence/cut set should not be below the range of ~0.0001 to 0.00001 (5.3.3.5).
The post-initiator HEPs (excluding the screening HEPs) should be reasonable from two standpoints: (1) first and foremost, relative to each other (i.e., the probabilistic ranking of the failures when compared one to another), and (2) in absolute terms (i.e., each HEP value), given the context and combination of positive and negative PSFs and their relative strengths. Example evaluation techniques include consideration of actual plant history, comparisons with results of other analyses, and qualitative understanding of the actions and their contexts by experts (5.3.3.8).</td></tr>
</table>

B.4.3 QUANTIFICATION – DEPENDENCIES

Potential dependencies between human failure events should be properly characterized and taken into account to ensure that the accident sequence frequency estimations are performed correctly taking into account any commonalities and relationships among the HFEs. The following dependencies shall be systematically considered:

- Dependencies within a task, where a task is defined as a group of actions that relate to a specific goal or system function.
- Dependencies among Category A actions.
- Dependencies between Category B and C actions within the same accident sequence.
- Dependencies among Category C actions within the same accident sequence.
- Dependencies between recovery actions and any other HFEs assessed.

As an example, when assessing pre-initiators multiple recoveries may be acceptable, but any dependencies among the initial failure and the recoveries, and among the recoveries themselves, must be considered. Examples of recovery factors include testing, independent verification, scheduled checks, and compelling signals.

A main concern related to pre-initiators is human-related “common-cause factors” that would lead to similar errors occurring across similar systems. The impact of recovery factors should be included in evaluating dependencies, and if dependencies across redundant trains are considered, care should be taken to remove corresponding human failure events contributions already included in the CCF data, to avoid double counting.

Dependencies among the post-initiator HEPs in an accident sequence should be quantitatively accounted for by virtue of the joint probability used for the HEPs.

Examples of factors that may influence the degree of dependencies among HFEs are given below.

Table 15 Appendix B – Factors influencing the degree of dependencies

Factors of importance for assessment of dependencies
"Good Practice" document (No. {3} in Table 6)

• the same crew member(s) is responsible for the acts,
• the actions take place relatively close in time in the sense that a crew "mindset" or interpretation of the situation might carry over from one event to the next,
• the procedures and cues used along with the plant conditions related to performing the actions are identical (or nearly so) or related, and
  * the applicable steps in the procedures have few or no other steps in between the applicable steps,
• there are similar PSFs for performing the acts,
• how the actions are performed is similar and they are performed in or near the same location, and
  * the interpretation of the need for one action might bear on the crew's decision regarding the need for another action

IAEA-TECDOC-1511 (No. {2} in Table 6)
• use of common cues; • responses called for in the same procedure; • closeness in time of cues or required actions; • increased stress caused by failure of the first response.

The degree of dependence between HFEs appearing in the same accident sequence or cut set is assessed. A conditional probability of the second, third, etc. event, given failure of the first, second, etc. shall be evaluated. The assumption of independence between HFEs shall be justified.

Due to the nature of the dependencies, the uncertainties they introduce and the impact that they will impose on joint failure probabilities, the following guidance is given regarding minimum joint failure probabilities:

<u>"Good Practice" document (No. {3} in Table 6):</u>

- Once all the relationships are considered and the dependencies are included in the HEP values, the total combined probability of all the HFEs in the same accident sequence/cut set should not be below the range of ~1E-04 to 1E-05.

<u>ENSI PSA Guide (No. {6} in Table 6).</u>

- The minimum joint failure probability for Category C actions within an accident sequence is 1E-05. For sequences that include actions that are supported by the emergency response team, the applicable minimum joint failure probability can be reduced to 1E-06.

B.4.4 QUANTIFICATION – UNCERTAINTIES

Uncertainties shall be estimated for all HEPs taken into account the variability in individual human performance as well as the scenario-specific influences on the action. The uncertainties in the HEPs are performed at least for the significant HEPs to the extent that these uncertainties need to be understood and addressed in order to make appropriate risk-related decisions.

Typical assessments of uncertainty involve developing uncertainty distributions for the HEPs, propagating uncertainty distributions for the HEPs through the quantitative analysis of the entire PRA, performing sensitivity analyses that demonstrate the effects on the risk results for extreme estimates in the HEPs based on at least the expected uncertainty range, or addressing through qualitative arguments.

Aleatoric and epistemic (erroneous modelling due to lack of knowledge) uncertainties should be addressed and the uncertainty assessment shall be consistent with the quantification method.

Causes of epistemic uncertainty may include:

- A credible (with hindsight) error mechanism may not have been identified by the assessor(s);
- A so-called ‘error of commission’ (EOC) - unidentified at the time of assessment - may occur with a higher probability than the assessed minimal cutset (leading to another initiating event);
- The assessor’s assumptions about the prevailing conditions and operational safety culture may prove to be incorrect.

In principle the following options for uncertainty assessment exist (document {5} in Table 6):

a. Not quantified
b. Quantified, global assignment to the final HEP point estimate.
c. Quantified, based on input uncertainties

B.4.5 QUANTIFICATION – RECOVERIES

The guidance on how to incorporate recovery actions into the HEP assessment below is taken from the "Good Practice" document (No. {3} in Table 6).

Based on the failed functions, systems, or components, identify recovery actions to be credited that are not already included in the PSA (e.g., aligning another backup system not already accounted for) and that are appropriate to be tried by the crew to recover the failure. Aspects to consider include the following examples:

- whether the cues will be clear and provided in time to indicate the need for a recovery action,
- the most logical recovery actions for the failure based on the cues that will be provided,
- whether the recovery is a repair action (e.g., the replacement of a motor on a valve so that it can be operated),
- whether sufficient time is available,
- whether sufficient crew resources exist to perform the recovery(ies),
- whether there is procedure guidance to perform the recovery(ies),

- whether the crew has trained on the recovery action(s) including the quality and frequency of the training,
- whether the equipment needed to perform the recovery(ies) is accessible and in a non-threatening environment (e.g., extreme radiation), and
- whether the equipment needed to perform the recovery(ies) is available in the context of other failures and the initiator for the sequence/cut set

Particular attention should be paid to accounting for dependencies among the HFEs including the credited recovery actions.

The probability of failing to perform the recovery(ies) can be quantified by (1) using representative data that exists and deemed appropriate for the recovery event, or (2) using the HRA method/tool(s) used for the other HFEs (i.e., using an analytical/modelling approach). If using data, ensure the data are applicable for the plant/sequence context or that the data are modified accordingly.

B.4.6 QUANTIFICATION – MINIMUM BELIEVABLE RESULTS

The information below represents a summary of international guidance documents related to lowest reasonable HEP values, i.e. what limitations and guidance can be found on when and how to use "low" HEP values. The summary is mainly based on reference documents No. {3} and {6} in Table 6 together with reference [1] (PSAM9 paper).

From the Swiss PSA guidance document (No. {6} in Table 6) the following criteria can be found:

- HEPs lower than 1E-05 (mean) are not accepted. For assessment of actions that are based on the decision of the emergency response team [10], a lower limit of 5E-03 (mean) shall be applied.
- The minimum joint failure probability for Category C actions within an accident sequence is 1E-05. For sequences that include actions that are supported by the emergency response team, the applicable minimum joint failure probability can be reduced to 1E-06.

Similar criteria can be found in "Good Practice" document (No. {3} in Table 6):

- The total combined probability of all the HFEs in the same accident sequence/cutset should not be below the range of 1E-04 to 1E-05.

As stated in the reference [1] Most Human Error Probabilities are within the range 1E-4 to 1.0, and there are certainly data to support these levels of human reliability. However, sometimes in quantified safety cases or probabilistic safety assessments, scenarios arise which require quantification of a human error sequence which seems incredible, or extremely unlikely.

[10] In case of accident conditions arising at a nuclear power plant additional personnel will be summoned to support the on-site decision making. The roles and responsibilities for this Emergency Response Team may differ between plants and also depending on the severity of the conditions.

Incident and accident experience, as well as human error data collection efforts and general expert opinion, appears to recognize the value of 1E-4 for a single human error, and 1E-5 for a set of human errors by different people, as ‘credibility thresholds’ in HRA.

This means that, for example, a cutset HEP of 1E-6 for a single error or indeed a team of people committing errors would require significant justification additional to the proper use of a respected HRA technique. In short, without additional supporting evidence, analysis or argumentation, such a number would be viewed with scepticism and may prove unacceptable. The reasons it may prove wrong are associated with what is known as epistemic uncertainty (i.e. modelling uncertainty – not knowing if all risk pathways and events have been identified). Causes of epistemic uncertainty are listed in section B.4.4.

It is further recognized in reference [1] that in cases where no error mechanism is evident (after effort has been spent searching for such mechanisms via task analysis or other methods), and particularly where operational experience is good, **‘capping’ the human performance at 1E-5 may lead to perceived over-engineering of the plant equipment**. The HRA or PSA assessor may therefore seek to justify a lower cut-off value than 1E-5, justifying such a value with further evidence and argumentation.

It shall be noted that the purpose of the guidance presented in [1] are related to Human Performance Limiting Values (HPLVs) and these are not HEPs – they can only be used to limit already modelled HEPs. In most practical cases, HPLVs are not dominant, as the other modelled HEPs are often at least an order of magnitude higher than the accompanying HPLV. The practical application would join the HPLV to the cutset in question via an OR gate if using a fault tree approach, as shown in figure below.

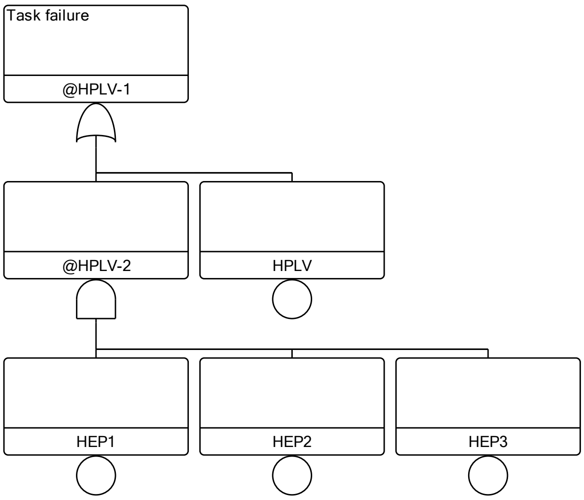

Figure 4 Appendix B – Incorporating HPLVs into fault tree model

The absolute lowest limit HPLV (effectively a ‘not-credible’ argument) is 1E-7 for straightforward tasks in post-trip scenarios where performance shaping factor are optimal.

Table 16 Appendix B – Guidance for assigning HPLVs

<table>
<tr><th>Guidance for assigning HPLVs (ref. [1])</th></tr>
<tr><td>Carry out normal HRA process including dependency modelling.</td></tr>
<tr><td>Identify low probability cut-sets or human event sequences that touch or cross the 1E-4 threshold for single operator scenarios, and 1E-5 for sequences or events involving more than one operator.</td></tr>
<tr><td>Apply HPLV to the appropriate cutset for single and multi-operator scenarios (1E-4 and 1E-5 respectively).</td></tr>
<tr><td>If real and relevant data exist, such data should be used in preference to HPLVs.</td></tr>
<tr><td>For any HPLV usage, task analysis should be carried out (if not already done so) to ensure that the task is adequately understood and that no additional error mechanisms exist that should be separately modelled. If new error mechanisms are identified, their subsequent modelling and quantification (including direct dependence) may obviate the need to use an HPLV (because the cutset probability may no longer cross the HPLV ‘threshold’).</td></tr>
<tr><td>The final assessment phase concerns scenarios where there is what is referred to as the ‘credibility conundrum’. In such cases, there is no clear mechanism of failure, and there is no rational explanation as to why operators would not achieve their goal, see below for further guidance on optimizing factors supporting this; if all are shown to be true by the assessor four final possible ways forward are available:
a. Declare the scenario not credible, and have such a declaration independently ratified within the safety management structure responsible for the PSA.
b. Adopt an HPLV or bounding limit of 1E-6 for the scenario, or 1E-7 for a scenario with excessive timescales (>12 hours) and insert into the PSA.
c. Make an ALARP (As Low As Reasonably Practicable) case
d. Re-design the task and re-assess.</td></tr>
<tr><td>Optimizing factors:
* Straightforward, trained and well-understood task led by symptom based procedures.
* Required equipment and instrumentation available.
* Need for action signalled strongly/repetitively via diverse and sustained high-level alarms/events.
* Excessive time available (more than triple the time needed to perform the action).
* No credible human failure mechanism identified (including via operational experience review and critical incident reviews) other than perverse or extreme ones.
* No improvement measure identifiable.
* New staff will arrive via shift change and/or new emergency technical advisor(s).</td></tr>
</table>

B.4.7 QUANTIFICATION – ACTIONS WITHOUT PROCEDURE

The importance of procedures and training is often mentioned in HRA guidance documents, i.e. whether the action is supported by procedures and if the actions have been part of training or not. It is therefore not surprising to find that existence and quality of procedures and frequency of training are common PSFs that are taken into account.

Another important aspect that often is demonstrated with procedures is if the actions and how they are analysed and modelled are plant-/task-specific and it is common to refer to plant-/task-specific procedures and how they have been taken into account when demonstrating that these features have been taken into account.

This can be exemplified with §§ 5.105 and 5.107 in IAEA SSG-3 [2] which states the following:

"*5.105. A systematic* ***review of plant procedures should be carried out*** *to identify the critical actions that will need to be carried out by plant operators after the occurrence of an initiating event (Type C human interactions). The review should determine the potential for errors to occur and the effect of these potential errors on the unavailability or failure of a component or system. Type C human interactions usually provide a significant contribution to the core damage frequency and hence are often the most important human interactions identified in the Level 1 PSA.*"

"*5.107. The human error probabilities derived should be scenario specific and should* ***reflect*** *the factors that can influence the performance of operators, including the level of stress, the time available to carry out the task,* ***the availability of operating procedures****, the level of training provided, the environmental conditions, etc. These factors (often called 'performance shaping factors') should be identified by task analysis.*"

Even though none of the examined guidance document specifically says that an action needs to be supported by a procedure in order to be taken into account they do not explicitly give any guidance on how to take into account if an action is more skill-based where a procedure may not be needed or do not exist.

B.4.8 QUANTIFICATION – HRA FOR HAZARDS

Most of the guidance documents that have been studied are focused on providing guidance on internal events PSA but as stated in the Good Practice" document (No. {3} in Table 6) the guidance should also be useful for other applications such as external events PSA (hazards).

The only specific guidance that has been found is related to specific PSFs that should be taken into account for external events, see section B.3.2. The specific PSFs during hazard conditions are also repeated here.

Table 17 Appendix B – Specific conditions for hazard conditions

Specific conditions that shall be taken into account when performing HRA for hazards according to ENSI PSA Guide (No. {6} in Table 6).
General conditions for internal and external hazards: • Increased stress and confusion. • Reduced availability of personnel. • Limited accessibility and habitability of relevant areas (e.g. rooms). • Failed or erroneous instrument indications. • Additional workload on personnel. • Additional difficulties in the detection/diagnosis of certain hazards. • Limited accessibility to areas of the plant. • Adverse environmental aspects caused by fire/flooding
Specific aspects that need to be considered for earthquakes • Choice of parameters that characterize an earthquake and their assumed effect on the error probabilities shall be defined and justified. • The approach applied and the numerical values (such as increase factors) shall be defined and justified. • The psychological and possibly physical effects of the earthquake shall be taken into account during HEP assessment.

B.5 VERIFICATION & VALIDATION – INTRODUCTION

Little or no guidance exist on how to verify and/or validate HRA results. Some guidance can however be found the PSA HRA review guideline (document {5} in Table 6) in terms of some definitions of "failure-guaranteeing conditions (FGCs)" related to post-initiator actions.

Table 18 Appendix B – Example of V&V check list

Types and examples of failure-guaranteeing conditions for a Cat. C safety actions (No. {5} in Table 6)	
Conditions required for action feasibility	**Failure guaranteeing condition (FGC)**
Personnel available: action can be performed with the available staff	FGC.l. **Essential lack of personnel**, e. g., • no qualified person available to perform the required action
Technical feasibility: action can be physically implemented in the scenario	FGC.2. **Essential technical barrier**, e. g., • reactor protection system inhibits action • action needs to be performed in a highly contaminated area • inaccessible performance location • performance tools destroyed by fire
Feasibility in time: action can be performed within the given time window	FGC.3. **Essential time barrier**, e. g., • very short time window available and fast performance is unlikely (complexity of thinking required for diagnosis, many steps required for execution)
Information available: need of action is identifiable in the scenario	FGC.4. **Essential information barrier**, e. g., • primary indicator required for diagnosis not present and alternative indicators are not available or their use is not practiced • action is neither known from training nor stated in the procedure

Types and examples of failure-guaranteeing conditions for a Cat. C safety actions (No. {5} in Table 6)	
Administrative compliance: action is conforming to basic safety rules	FGC.5. **Essential administrative barrier**, e. g., • well-known safety rule prohibits to take the action

B.5.1 VERIFICATION & VALIDATION – REASONABLENESS

The reasonableness of the estimated HEPs should be checked mainly from two standpoints:

a. first and foremost, relative to each other (i.e., the probabilistic ranking of the failures when compared one to another), and

b. in absolute terms (i.e., each HEP value), given the relative strengths of the positive and negative PSFs identified as being important and the presence or absence of recovery factors.

Example evaluation techniques include consideration of actual plant history, comparisons with results of other analyses, and qualitative understanding of the actions and their contexts by experts. As an example for pre-initiator actions the reasonableness of the HEP estimates should be checked by confirming that there has not been a significant history of restoration failures or miscalibration issues.

Another evaluation that should be done is to check that very low HEP values comply with best practice, see sections below.

Table 19 Appendix B – Review criteria related to reasonableness

Review criteria related to reasonableness (No. {5} in Table 6)	
Reasonable error selection results	• Reasonable number of Cat. A errors selected for quantification? • Reasonable number of Cat. C safety actions selected for quantification?
Reasonable quantification results	• Important errors are quantified by 'realistic' HEPs? • Credible HEP results compared with other PSA studies? • Are the quantification results used to improve safety insights?

B.5.2 VERIFICATION & VALIDATION – TRANSPARENCY

Several of the international guidance documents emphasize the importance of transparency. Whatever the approach taken when performing the HRA, it needs to be defensible and transparent, and able to filter out the key issues and risk-significant priorities. An analysis is "transparent" if an externally qualified person is able to reproduce the analysis results.

Below some review criteria are given related to transparency.

Table 20 Appendix B – Review criteria related to transparency

Review criteria related to transparency (No. {5} in Table 6)	
Transparent error selection process	• Process of searching for critical errors identifiable? • Error selection criteria/rules presented?
Reproducible error selection results	• Reproducible or conservative selection criteria/rules? • Inclusions (of errors) clearly documented? • Obvious exclusions (of errors) clearly documented?
Transparent quantification methodology	• Methodology information (published reference or description in PSA report) presented? • Is it basically clear how each method generates HEPs? • Identifiable quantification method for each included error?
Reproducible methodology implementation	• PSA integration details are clear from the error descriptions provided? • Implementation of quantification methodology documented? • Formal, and traceable, HEP assessment documentation exists?
Transparent quantification results	• HEPs are clearly identifiable for the errors quantified? • Important measures are clearly identifiable for a significant subset of the errors?

B.5.3 VERIFICATION & VALIDATION – ADEQUACY

In the same way as transparency the international guidance also emphasize the importance of the HRA assessment being adequate. An analysis is "adequate" if the results reflect the plant-specific conditions related to safety.

Below some review criteria are given related to adequacy.

Table 21 Appendix B – Review criteria related to adequacy

Review criteria related to adequacy (No. {5} in Table 6)	
Adequate error selection process	• Comprehensive process of searching for critical errors? • Category A (pre-initiator) errors addressed? • Category B (initiator) errors addressed? • Category C (pre-initiator) safety actions addressed? • References to performances, practices and intervention constraints presented? • Reasonable selection criteria/rules?
Adequate quantification methodology	• Methodology addresses plant/task specific inputs? • Methodology is applied within its scope of application?
Adequate methodology implementation	• Methodology implementation refers to plant/task-specific inputs? • Global dependencies (between errors) addressed? • HEP uncertainties quantified adequately?

APPENDIX C – METHODS TO IDENTIFY ACTIONS WITH POSSIBLE DEPENDENCIES

C.1 METHOD NO. 1 – RE-QUANTIFICATION AFTER SETTING HEP = 1

The most thorough method is to assign HEP = 1 for all basic events that represents the operator actions of interest and then re-quantify the entire PSA, e.g. PSA Level 1 for internal events. Changing the HEP values is preferably done using exchange events in RiskSpectrum® in order to keep the original model intact. This method requires a time consuming re-quantification, which however ensures that any cutset that was previously truncated due to cut-off values applied will appear in the cutset list as long as the total frequency of the cutset is higher than the cut-off value. Also setting HEP = 1 for all basic events does not only mean that all operator actions will fail, it also means that complete dependency is assumed for any operator actions that appears together with another operator actions.

C.2 METHOD NO. 2 – USING POST PROCESSING RULES IN ORDER TO SET HEP = 1

A probably faster way of performing a similar task as the method above is to use Post Processing rules in RiskSpectrum®. By setting up rules that will change the original operator action basic events to basic events with Q = 1 the same result will be achieved as in method No. 1. The drawback is however that the analyst must be certain that the cutset list contains a proper number of cutsets so that no relevant cutset that has been truncated due to cut-off. In that case, this cutset will not appear when applying the Post Processing rules.

C.3 METHOD NO. 3 – MANUAL CHANGING OF HEP USING MCS EDITOR

The third method uses the MCS Editor in RiskSpectrum in order to identify cutset that contains multiple operator action basic events. When a cutset list is opened in the MCS Editor it is possible to manually change the failure probability of all events (basic events and CCF events) in the list. The cutset list can then be sorted and thereby showing to the analyst if there are any cutset that contains multiple operator actions that may have a significant impact on the result due to dependencies. This method has the same drawback as for the Post Processing rules, no re-generation of the cutset list will be made and hence any cutset that has been truncated due to cut-off will not participate in the analysis.

C.4 METHOD NO. 4 – AUTOMATIC CHANGING OF HEP USING FAULT TREE LOGIC, SWISS EXAMPLE

The minimum joint failure probability for Category C actions within an accident sequence shall be considered, e.g. HRA CCF = 1E-5.

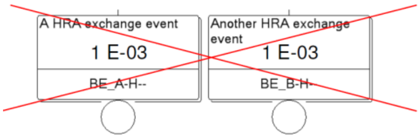

Figure 5 Appendix C – Example of multiple actions with too low joint failure probability

The HRA CCF Failure mode is added into the fault tree logic to take this into account.

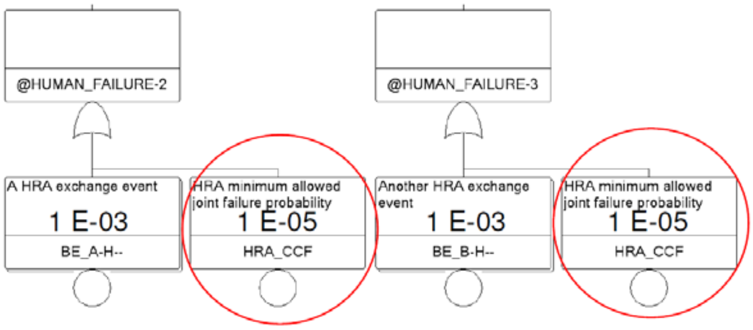

Figure 6 Appendix C – Introducing HRA CCF event in fault trees

Dominant cutset: HRA_CCF. I.e. ENSI's requirement is fulfilled without post-processing, but information is lost.

An alternative way to introduce the HRA CCF failure mode is if added into the fault tree logic together with an information place holder, e.g. BE_A-HPH (with HEP = 1).

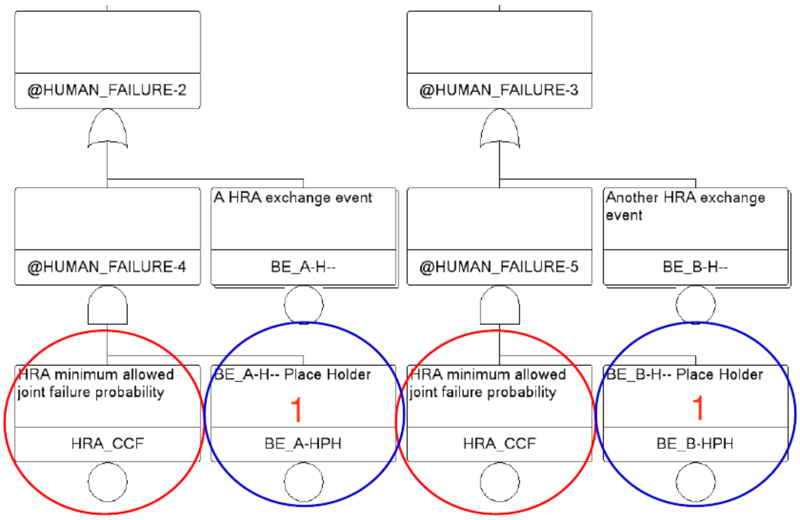

Figure 7 Appendix C – HRA CCF event with place holder

Dominant cutset: HRA_CCF * BE_A-HPH (HEP = 1) * BE_B-HPH (HEP = 1): The minimum joint failure probability requirements have been fulfilled. Analyses are 'best estimates' (not too conservative, not too optimistic). Automation and script language have made the implementation manageable. Information concerning dominant scenarios is not lost.

APPENDIX D – COMPARISON AGAINST ASME PRA STANDARD

The attributes used to organize this report are compared with the ASME [8] requirements to provide an overview of what parts of the ASME that are covered in the practical guide. This is done to provide a cross reference between this guide and the ASME requirements. In addition does the table in Appendix D provide a completeness check to ensure that a full set of recommendations have been provided in relation to the capability categories defined in the standard.

The capability categories defined in the ASME have not been evaluated to determine exactly what level of capability that is achieved if all our recommendations are met.

As conclusion it can be stated that practical guidance and recommendations are provide for all areas in ASME.

Table 22 Appendix D – Comparison with the ASME requirements

ASME	HFE Definition				
	Selection	**Data collection**	**Qualitative analysis**	**Quantification**	**V&V**
Pre-Initiator High level requirement	HLR-HR-A HLR-HR-B HLR-HR-C	HLR-HR-C	HLR-HR-C HLR-HR-D	HLR-HR-A HLR-HR-D	HLR-HR-D
Post-Initiator High level requirement	HLR-HR-E	HLR-HR-E HLR-HR-F HLR-HR-H	HLR-HR-F HLR-HR-G	HLR-HR-G HLR-HR-H	HLR-HR-G HLR-HR-I
Supporting requirement	Identification HR-A1 HR-A2 HR-C1 HR-E1 HR-E2	Plant organization / management	Task analysis HR-D2 HR-D3 HR-F2	Methodology HR-D1 HR-G2	Reasonableness HR-D7
				PSF calculation HR-D2 HR-G4 HR-G5 HR-H2	HR-G6
	Screening HR-B1 HR-B2	Task specific information HR-E3		Dependencies HR-A3 HR-B2 HR-D5 HR-G7 HR-H3	Transparency HR-I1
				Uncertainties HR-D6 HR-G8	
			PSF Assessment HR-G1 HR-G3	Recoveries (see H1-H3)	
	Errors of Commission	Task context HR-C2 HR-C3 HR-E4 HR-F1 HR-H1		Minimum believable results HR-D4	Adequacy HR-I3 (as identified in[11] QU-E1 and QU-E2)
				Actions without procedures	
				HRA for hazards	
	Documentation HR-I2				
	HRA Team				

[11] HLR-QU-E Uncertainties in the PRA results shall be characterized. Sources of model uncertainty and related assumptions shall be identified, and their potential impact on the results understood.

Table 23 Appendix D – ASME high level requirements

Designator	Requirement
Pre-Initiator HRA	
HLR-HR-A	A systematic process shall be used to identify those specific routine activities that, if not completed correctly, may impact the availability of equipment necessary to perform system function modelling in the PRA.
HLR-HR-B	Screening of activities that need not be addressed explicitly in the model shall be based on an assessment of how plant-specific operational practices limit the likelihood of errors in such activities.
HLR-HR-C	For each activity that is not screened, an appropriate human failure event (HFE) shall be defined to characterize the impact of the failure as an unavailability of a component, system, or function modelled in the PRA.
HLR-HR-D	The assessment of the probabilities of the pre-initiator human failure events shall be performed by using a systematic process that addresses the plant-specific and activity- specific influences on human performance.
Post-Initiator HRA	
HLR-HR-E	A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the accident sequences.
HLR-HR-F	Human failure events shall be defined that represent the impact of not properly performing the required responses, in a manner consistent with the structure and level of detail of the accident sequences.
HLR-HR-G	The assessment of the probabilities of the post-initiator HFEs shall be performed using a well-defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence.
HLR-HR-H	Recovery actions (at the cutset or scenario level) shall be modelled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario.
Pre- and Post-Initiator HRA	
HLR-HR-I	Documentation of the human reliability analysis shall be consistent with the applicable supporting requirements (HLR-HR-I).